Polish Federation of Land Battle in a Distributed Interactive Environment

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ABSTRACT

Polish distributed and interactive environment for training of combat or peace support operations is presented. As a starting point in modelling process a specific theoretical game is considered. Game theory offers good "language of conflict". So we define military conflict game in general sense and transit it to the next phases of modelling – combat process model, decision model, and simulation model. The distribution of conflict model components is natural and results from the real system's component distribution. The generic model of combat process as a multivariate stochastic process is concerned. The transition between the stochastic model and simulation model is shown. The global decision problem is formulated for each side as a stochastic programming problem with many criteria. The main conclusion of the theoretical analysis is the decision variable in such complex situation there is a decision rule and the criterion can be considered as a risk function, defined on the basis of predicted losses. However, real decision process seems to be far from optimal solution, we should indicate the direction of improvement.

Each component of the battle system is described as an object, which has many attributes. The objects' behaviour during the gaming is represented as a simulation process. The local conflict models with input data determined are applied for particular analyses of decisions considered by players. The system components' distribution, communication and synchronisation mechanisms are presented. A prototype of the system so called MSCombat is constructed. The environment proposed is built as an opened system on the basis of formal model and can be developed and improved. The first approach to the distributed communication and computational problem was on the basis of CORBA. The evolution of the prototype from the aggregation of combat models and simplification of land battle to more sophisticated and professional simulation system for CAX is concerned.

The second version of MSCombat was built as a federation according to FEDEP. The different RTIs (DMSO 1.3. NG, pRTI) were used to the implementation and compared in the execution process. Polish federation of land battle is constructed with respect to FOM of DiMuNDS 2000, so the possible cooperation is considered. The financial aspect of the simulation environment development is presented as very complicated process of two stage competition. The prototype was the basis of our position in the competition. It enables preparing of proper offer and after winning good concept of professional simulation system for CAX and combat analyses. The cooperation of many experts, teams from different sources due to the final product is concerned.

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INTRODUCTION

The methodology of modelling and interactive simulation of military conflict for computer assisted exercises and decision support systems is presented. The essence of the approach consists in the imitation of military actions in real situations with a feasibility of the decision process effects' observation. A theoretical game is considered as a basic model of a military conflict. The strategies of players are formulated on the basis of a combat process model that is defined as a multivariate stochastic process. The stochastic model expresses the uncertainty in a conflict situation. There exists the possibility of observation of the battlefield and making decisions on the basis of these measurements. Having known the conditional distributions of observed feature in the battlefield, it is possible to determine decision functions and then estimate a strategy. The multistage stochastic optimisation problem is formulated in order to find an estimation of each side, optimal strategy in a military conflict situation. It seems to be impossible to find, in a sense, the optimal solution in the general formulation (23), (25), so we propose a specific way of generating trajectories of stochastic combat process taking into account decisions made during a military operation. The prototype of an interactive simulator for the combat process analysis was built on the basis of the multivariate stochastic process. The constraint sets and solutions of the stochastic optimisation problem are determined during the simulation running. Each component of the battle system is described as an object, which has got many attributes. The object behaviour during the game is represented as a simulation process. The models of local conflicts with input data determined by players or decision procedures are applied for particular analyses. The combat models for local clashes are implemented. There are two points of view to the modelling. First of all there is decision support in real conflicts, secondly there is a training of decision-makers in conflict situations. So we should take into account in the modelling process the following conditions: dynamics, uncertainty, uncompleted information, human interactions, surprise, counteractions, counter-counteractions and so on. As a starting point in modelling process a specific theoretical game is considered. Game theory offers good "language of conflict". So we define military conflict game in general sense and transit it to the next phases of modelling – battle process model, decision model, and simulation model. The distribution of conflict model components is natural and results from the real system's component distribution. It is very interested, how to reflect the real combat process with respect the decisions made by sides of conflict. How to design such infrastructure which enables proper and effective training of commanders or deep analysis of real conflict. Having a prototype allows us to analyse many performance measures connected with distributed simulation environment and thus to use these results in designing process of professional simulation system for CAX.

NON-COALITION GAME UNDER UNCERTAINTY CONDITIONS

Let us consider the four-person game:

$$\Gamma^{w} = < \{1,2,3,4\}, \{S^{w}_{k}\}_{k\in\{1,2,3,4\}}, \{H^{w}_{k}\}_{k\in\{1,3,4\}} >, \tag{1}$$

which represents a military conflict with peacekeeping forces contribution. The first and the third players represent opposite fighting sides, the fourth player represents the peacekeeping forces and the second player represents the nature (in wide sense a battlefield: battle space, weather, random results of duels and gun fire,...), S_k^w *(k=1,2,3,4)* denotes a set of strategies of player *k*, and H_k^w – payoff function of player *k* (*k*=1,3,4). If peacekeeping forces support one of the conflict side then we have the situation with three players (Najgebauer 1999a).

The strategies of player number one and three are their plans of fighting (movement, fire allocation) and strategy of player four is plan of peacekeeping operations. The strategies of the nature are represented by states of the nature. However, it is difficult to say about payoffs for the nature in a game situation.

Decisions of sides depend on the nature state observed by them. For real state of the nature $\Theta \in \Omega$, where Ω – set of nature states, the game situation can be formulated as follows:

$$s^w = (s_1^w, \Theta, s_3^w, s_4^w),$$
$$s_1^w \in S_1^w, \Theta \in \Omega, s_3^w \in S_3^w, s_4^w \in S_4^w \tag{2}$$

and the payoff function for players 1, 3 and 4 :

$$H_k^w : S_1^w \times \Omega \times S_3^w \times S_4^w \to R, \; k = 1,3,4 \tag{3}$$

In real situations the decision-makers do not know actual state of the nature and decisions of the enemy, so they realise the observation process of the nature state. We can assume, that they observe random variables Φ_k (k=1,3,4), which have distributions dependent on state Θ. The conditional distribution of random variable Φ_k is denoted by $F(\phi^k|\Theta)$. The set of possible n-component samples can be described as the sample space $\widetilde{\mathbf{\Phi}}_k$ of player k. We can define decision rules as follows:

Definition 1.

Function $d^k(\phi^k)$, defined by:

$$d^k : \widetilde{\mathbf{\Phi}}_k \to S_k^w, k \in \{1,3,4\},$$
$$\phi^k \in \widetilde{\mathbf{\Phi}}_k, s_k^w \in S_k^w, k \in \{1,3,4\}, \tag{4}$$
$$d^k(\phi^k) = s_k^w, \; k \in \{1,3,4\}.$$

we denotes as non-randomised decision function of the player k.

The set of all decision functions d^k is denoted by D_k (k=1,3,4). The payoff function of the player k is a random variable for a given state of nature because it depends on the state and the values $d^1(\Phi_1)$, $d^3(\Phi_3)$, $d^4(\Phi_4)$, where Φ_1, Φ_3, Φ_4 are random vectors with conditional distributions $F_1(\phi^1|\Theta)$, $F_3(\phi^3|\Theta)$, and $F_4(\phi^4|\Theta)$ respectively. So we propose a new payoff function:

$$\widetilde{H}_k^w : D_1 \times \Omega \times D_3 \times D_4 \to R \tag{5}$$

which can be a parameter for random payoff function (3). The "least safe" parameter, under the military conflict conditions, is the expected value of H_k^w :

$$\widetilde{H}_k^w(d^1, \Theta, d^3, d^4) = E_\Theta H_k^w(d^1(\Phi_k), \Theta, d^3(\Phi_k), d^4(\Phi_k)) =$$
$$= \int_{\Phi_k} H_k^w(d^1(\Phi_k), \Theta, d^3(\Phi_k), d^4(\Phi_k)) dF_k(\phi^k \mid \Theta) \tag{6}$$

It is possible to determine the variance of H_k^w and then the new payoff function will be two-dimensional.

The other way is to determine a quantile $\widetilde{h}_{q_k}^w$ of the distribution of variable H_k^w ($q_k \in [0,1]$):

$$\widetilde{h}_{q_k}^w = \inf\{h_{q_k}^w : P(H_k^w(d^1(\Phi_1), \Theta, d^3(\Phi_3), d^4(\Phi_4)) \le h_{q_k}^w) \ge q_k \text{ and} \tag{7}$$
$$P(d^1(\Phi_1), \Theta, d^3(\Phi_3), d^4(\Phi_4)) \ge h_{q_k}^w) \ge 1 - q_k\}$$

and then

$$\widetilde{H}_k^w(d^1, \Theta, d^3, d^4) = \widetilde{h}_{q_k}^w.$$

So we can define the relaxation of game (1) for military conflict:

$$\widetilde{\Gamma}^{w} =< \{1,2,3,4\}, \{D_1, \Omega, D_3, D_4\}, \{\widetilde{h}^{w}_{qk}\}_{k\in\{1,3,4\}} > \qquad (8)$$

If we reduce the number of the players in the game (8), we will obtain the game:

$$\widetilde{\Gamma}^{w'} =< \{1,2\}, \{D_1, \Omega\}, \{\widetilde{h}^{w}_{q1}\} > \qquad (9)$$

which can represent a model of disaster, where D_1 denotes a set of decision rules of anti-crisis centre (player 1), and the set Ω describes nature states (player 2) as destroy process states, analogously to the combat process.

MATHEMATICAL MODEL OF COMBAT PROCESS

The presented model of battle process is considered from the decision point of view. We would like to present system's model with significant components and possible relations between them. The information is aggregated in the description to better take into account the whole process by the decision-maker. Three sides are proposed (A, B, C), where A, B represent the opposite sides and C represents peacekeeping allied forces.

Let $\{S(t), t \in [0,T]\}$ be the multidimensional stochastic process (Najgebauer 1999a), where:

$$\{S(t) = (S_{1Y}(t), S_{2Y}(t), S_{3Y}(t), S_{4Y}(t), S_{5Y}(t), S_{6Y}(t), S_{1PW}(t), S_{2PW}(t)), t \in [0,T], Y = A,B,C\}, \qquad (10)$$

- $S_{1Y}(t)$ – state of land fighting units of side Y (A, B or C) (command structure, state of readiness, current mission, region, where the side Y units are located, average velocity of the units, number of combatants, the level of training, morale, state of weapon, state of munitions and fuel, level of pollution),
- $S_{2Y}(t)$ – state of supporting units of side Y, (artillery and air forces), (analogously to fighting units),
- $S_{3Y}(t)$ – state of engineering units, (like above and state of engineering equipment),
- $S_{4Y}(t)$ – state of logistics system, (state of supplying bases, transportation system, infrastructure, renewal system, medical system),
- $S_{5Y}(t)$ – state of command and communication system, (state of communication nodes, state of communication net, state of command units),
- $S_{6Y}(t)$ – state of surveillance and electronic warfare units,
- $S_{1PW}(t)$ - state of terrain (cover , vegetation, industry, roads, buildings, fortification, engineering activities).

  The terrain model is discrete and can be expressed as follows:

  $Z=< G, \{\varphi_l\}_{l=1,2,4}, \{\varnothing\}>$,

  where $G =<W,U>$- Berge graph, W – set of vertices , U – set of arcs , $U \subset W\times W$

  φ_1: $W\to C$ – function, which describes a location of the zone, represented by vertex $w\in W$, (rectangle 200m x 200m) $C\subset R^3$, C describes the whole battlefield area of the conflict,

  φ_2: $W\to 2L$ function, which describes an assignment of roads to node w (these roads are accessible for mobility in a zone w), L- set of all road numbers in a battlefield,

φ_3: W × $J^{A(B,C)} \rightarrow 2^{TU}$ – assignment function of formation type subset to node w, TU – set of all possible types of combat units formation,

φ_4: W × $J^{A(B,C)} \rightarrow R^n$ – the determination of maximal velocities of combat units on roads of battlefield, n=|L|.

Arcs of the graph represent possibility of close transition between zones.

- $S_{2PW}(t)$ – state of environment – weather, electromagnetic situation, pollution situation at the moment t,

The process is discrete in states and continuous in time. The transitions between states are caused by combat actions, decisions and their realisations, natural phenomena,....

Each element of the battle system, which represents one of the sides or the battlefield, can be represented as an object. The transitions of the combat process are connected with events on the battlefield and their time is random variable. One of the important sources of randomness on the battlefield there are random results of the local clashes. We have proposed many stochastic models of the local conflict in a sense of locality as a closed combat process between two elementary combat units (process of combat units resource destroying).

The models have been recently developed within the confines of researches conducted in Military University of Technology, Cybernetics Faculty. One of them is the simulation combat model with dynamic fire control. It is an attempt of a description of two sides clashes at the battalion level. We assume that the combat is local. It means that combatants lead a direct fire into opponents under optical visibility and under similar terrain and atmospheric conditions. It is obvious that the locality assumption is not always true in the real world. However if we consider that the warfare applies to small formations which naturally operate in a local area, this simplification seems to be acceptable. Additional assumptions are as follows:

1) two sides of a battle A and B are equipped with heterogeneous armament weapons;
2) each of the weapon is characterized by different properties:
    a) p_{rs} – a probability of one shot hit by combat mean of type "r" to target s-type. The value of this parameter is not constant and depends on e.g.: a distance between opposing weapon systems, terrain and atmospheric conditions of a battlefield;
    b) λ_r – the fire intensity of r-th type combat mean. The parameter either is not constant and depends on e.g.: a level of logistics supplies (ammunition and fuel), a kind of a unit activity (attack, defence, movement);
    c) α_{rs} – the coefficient which characterizes a resistance of a specific r-type weapon from s-type weapon direct fire. It has a measure of a conditional probability of one shot killing when target has hit;
    d) D_r – the range of a effective fire of a r-type weapon. This parameter limits the specific weapon availability during a battle;

    where

    $r \in \{1,2,...,R\}$, $s \in \{1,2,...,S\}$

    and R, S represent numbers of weapon types for each conflict side (adequately A and B).

3) during the course of a battle there is no possibility of reinforcement (soldiers, ammunition, fuel);
4) the command, control and communication system works properly for both conflict sides.

Generally, the presented combat model describes a warfare like a multistage process of alternate optimal decisions calculation and their simulated realization. The decisions (for both A and B side respectively) apply to combat means allocation and there are determined in each stage of the battle process. The simulation of the decisions' effects for a chosen stage we can describe as a multidimensional stochastic semi-Markov process $\xi(t) = (\xi^A(t), \xi^B(t))$ of DC class (discrete in states and continuous in time). The effects of destroying interactions concern to the current armament.

$$\xi^A(t) = \left[\xi^A_{rs}(t)\right]_{R\times S}, \text{ where}$$

$\xi^A_{rs}(t)$ – represents a number of a r-type weapon of side A which has been allocated to fire to s-type weapon of side B.

THE DECISION PROCESS MODEL

During the modelling process, we take into account combat units as encapsulated objects with their internal structure, power, logistics and command, communication, intelligence subsystems. The operation plan is limited to the land units without special type of warfare like air-force support, artillery support. These components are considered in another way (Najgebauer, 1996) (and are included into the decision support system as tools). The modelling process is presented from one side point of view. The decision models for the rest sides can be analogical.

The terrain is considered as a discrete space. In the decision making process we must observe the battlefield and deviation of required trajectory of the battle process:

$$D(t) = \{D_i^t = <t_{i0,}(w_{i,m}^t, v_{i,m}^t, s_{i,m}^t, x_{i,m}^t, r_{i,m}^t)_{\, i=1,2\ldots,Mi}{}^t > i \in J^A\} \tag{11}$$

where

t_{i0} – start of action for *ith* combat unit,

$w_{i,m}{}^t$ – vertex of the net $\boldsymbol{Z}$, it is m^{th} vertex on the path, $v_{i,k}{}^{t}$ – i^{th} unit velocity on the m^{th} vertex, $s_{i,m}{}^t$ – formation type on the m^{th} vertex,

$x_{im}{}^t = (x_{i,k}{}^t(j))_{j=1,2,\ldots,J}{}^B$ – allocation of i^{th} unit fire,

$r_{i,m}{}^t$ – the number of wave, M_i^t – the number of vertices on the i^{th} unit path.

There are physical and tactical limits for a decision, which determine constrained set in a moment *t*.

$D^{A(B,C)}(t) \in \Delta^{A(B,C)}(t)$

The General Structure of Decision-Making Process

The whole decision process can be presented as follows:

Determining General Mission as a required subset of states of combat process $S_{sat}(T) \subset X$,

Measuring combat process state at the moment *t* (surveillance subsystem) – *n*-component sample $\xi = (\xi_1, \xi_1, \xi_1 \ldots \xi_n) \in \Xi_t$

Choice of the decision procedure:

g: $\Xi_t \to \Delta^A(t)$, $\xi \in \Xi_t$, $D(t) \in \Delta^A(t)$, $g(\xi) = D$(t), which extremises the decision-maker utility function χ, e.g. mean value of losses of side A or probability of event, that state of side A in T it is not far from $S_{sat}(T)$ than d^*

The next step (measuring....)

There are many guidelines for the commander, which must work out his decision. Let us consider a characteristic of combat process:

$$W_n(t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^Y) \tag{12}$$

Let us assume, that we can determine the conditional distribution of the characteristic:

$$\begin{aligned} &P\{W_n(t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^Y) < w / S(t) = s\} = \\ &= F_{W_n/S(t)}(w/s; t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^\mathbf{A}) \end{aligned}, \tag{13}$$

where $t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^\mathbf{A}$ there are parameters of combat process. Especially the decisions D^A, D^B, D^C can control of the combat process transitions.

Some of them can be as follows:

F1 – the difference of mission time realisation and mission complete planned on the higher level

$\varsigma_i^t, \partial^t : \Omega \to \mathbf{R}, i \in \mathbf{J}^A,$

$\partial^t = \max_{i \in J^A} |\varsigma_i^t - T^A|$

$$\begin{aligned} &F_1 : [t, T]^2 \times \mathbf{\Delta}^A(t) \times \mathbf{X} \times \mathbf{\Delta}^B(t) \times \mathbf{\Delta}^C(t) \times \mathbf{Q}^A \to \mathbf{R} \\ &F_1(t, T^A, D^A(t), s, D^B(t), D^C(t), \mathbf{Q}^A) = \\ &= \theta^t(\partial^t(t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^A) / S(t) = s) \end{aligned} \tag{14}$$

θ – parameter of random variable ∂^t- it means the biggest difference between termination time of combat units and time, which is determined for the side. The set of parameters $\mathbf{Q}^\mathbf{A}$ is given.

$D^A(t) \in \mathbf{\Delta}^A(t), S(t) \in \mathbf{X}, D^B(t) \in \mathbf{\Delta}^B(t), D^C(t) \in \mathbf{\Delta}^C(t)$

F_2 – the losses after the completion of mission:

$$\begin{aligned} &O^t : [t, T] \times \Omega \to \mathbf{R}, \\ &O^t(T^A) = S_{1A}(t) - S_{1A}(T^A). \end{aligned} \tag{15}$$

$$\begin{aligned} &F_2 : [t, T]^2 \times \mathbf{\Delta}^A(t) \times \mathbf{X} \times \mathbf{\Delta}^B(t) \times \mathbf{\Delta}^C(t) \times \mathbf{Q}^\mathbf{A} \to \mathbf{R} \\ &F_2(t, T^A, D^A(t), s, D^B(t), D^C(t), \mathbf{Q}^\mathbf{A}) = \\ &= \Theta^t(O^t(t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^\mathbf{A}) / S(t) = s) \end{aligned}$$

F_3 – the degree of the mission completion

$$
\begin{aligned}
&R_t^A : [t,T] \times \Omega \to \mathbf{R} \\
&F_3 : [t,T]^2 \times \mathbf{\Delta}^A(t) \times \mathbf{X} \times \mathbf{\Delta}^B(t) \times \mathbf{\Delta}^C(t) \times \mathbf{Q}^\mathbf{A} \to \mathbf{R} \\
&F_3(t, T^A, D^A(t), s, D^B(t), D^C(t), \mathbf{Q}^\mathbf{A}) = \\
&\beta^t(R_t^A((t, T^A, D^A(t), D^B(t), D^C(t), \mathbf{Q}^\mathbf{A}) / S(t) = s)
\end{aligned} \tag{16}
$$

$$
R_t^A(T^A) = \frac{\left(\sum_{m=1}^{M^A} \left| S_{0m}^A - S_m^A(T^A) \right|^p \right)^{\frac{1}{p}}}{\left(\sum_{m=1}^{M^B} \left| S_{0m}^B - S_m^B(T^A) \right|^p \right)^{\frac{1}{p}}}, \; p \ge 1 \tag{17}
$$

$$
R_t^C(T^C) = \left(\sum_{m=1}^{M^C} \left| S_{0m}^C - S_m^C(T^C) \right|^p \right)^{\frac{1}{p}}, \; p \ge 1
$$

F_4 – the possibility of actions at the moment τ

$$
\begin{aligned}
&Y_t^A : [t,T] \times \Omega \to \{0,1\} \\
&F_4 : [t,T]^2 \times \mathbf{\Delta}^A(t) \times \mathbf{X} \times \mathbf{\Delta}^B(t) \times \mathbf{\Delta}^C(t) \times \mathbf{Q}^A \to (0,1)
\end{aligned}
$$

$$
\begin{aligned}
&F_4(t, \tau, D^A(t), s, D^B(t), D^C(t), \mathbf{Q}^\mathbf{t}) = \\
&= \varepsilon_t^A(Y_t^A(t, \tau, D^A(t), D^B(t), D^C(t), \mathbf{Q}^\mathbf{t}) / S(t) = s)
\end{aligned} \tag{18}
$$

$$
Y_t^A(\tau, D^A(t), S(t), D^B(t), D^C(t)) = \begin{cases} 1, \text{where } S^A(\tau) \in \boldsymbol{S}_{\mathrm{Act}}^A, \tau \in [t,T] \\ 0, \text{where } S^A(\tau) \notin \boldsymbol{S}_{\mathrm{Act}}^A, \tau \in [t,T] \end{cases} \tag{19}
$$

ε_t^A – the parameter of conditional distribution of random variable Y^A.

Other criteria are possible.

Let us introduce the risk function to assess the decision process. We can use the description of general characteristics of combat process (10) and its expected value or position parameter (e.g. quantile):

$$
\begin{aligned}
&E(W_n(t, T^A, g^A(\Xi_t^A), D^B(t), D^C(t)) \mid \Xi_t^A = \xi_t^A, S(t) = s) = \\
&\hbar(\xi_t^A, s) = L^A(t, T^A, g^A(\xi_t^A), s, D^B(t), D^C(t))
\end{aligned} \tag{20}
$$

where $g^A(\xi_t^A) = D^A(t)$,

The risk function can be define:

$$
\chi^A : [t,T]^2 \times \boldsymbol{G}^A \times \boldsymbol{X} \times \mathit{\Delta}^B(t) \times \mathit{\Delta}^C(t) \to \mathbf{R}^2 \tag{21}
$$

$$
\begin{aligned}
&\chi^A(t, T^A, g^A, s, D^B(t), D^C(t)) = \\
&= (E(L^A(t, T^A, g^A(\Xi_t^A), S(t), D^B(t), D^C(t)) \mid S(t) = s), \\
&Var(L^A(t, T^A, g^A(\Xi_t^A), S(t), D^B(t), D^C(t)) \mid S(t) = s))
\end{aligned}
$$

or $$\chi^A : [t,T]^2 \times \mathbf{G}^A \times \mathbf{X} \times \Delta^B(t) \times \Delta^C(t) \times \mathbf{Q}^\mathbf{A} \to \mathbf{R}^k \tag{22}$$

where $k \geq 1$,

$$\chi^A(t, T^A, g^A, s, D^B(t), D^C(t)) = (\tilde{f}_k)_{k \geq 1},$$
where :
$$\tilde{f}_k = \inf\{f_k : P\{F_k(t, T^A, g^A(\Xi_t^A), S(t), D^B(t), D^C(t)) \leq f_k \mid$$
$$S(t) = s\} \geq q_k \text{, and}$$
$$P\{F_k(t, T^A, g^A(\Xi_t^A), S(t), D^B(t), D^C(t)) \geq f_k \mid S(t) = s\} \geq 1 - q_k\},$$
$S(t) \in \mathbf{X},\ q_k \in \mathbf{Q}^{\mathbf{A}}$ is given
if ξ_t^A is a realisation of Ξ_t^A, then
$$D^A(t) = g^A(\xi_t^A),$$
$t \in [0, T^A],\ F_k$ see. (2.15 - 2.20).

$\mathbf{G^A}$ – the set of decision procedures of the side A decision-maker.

The first formulation of decision problem could be one-criterion:

Stage 1. An observation Ξ_t (the distribution: $F(\xi_t^A / S(t), D^B(t), D^C(t))$ is determined),

Stage 2.

a) Find the decision function g^A, which minimise the maximal risk:

$$\max_{\mathbf{X} \times \Delta^B}(\chi^A(t, T^A, g_0^A, S(t), g^B, g^C)) =$$
$$= \min_{g^A \in G^A} \max_{X \times \Delta^B(t) \times \Delta^C(t)}(\chi^A(t, T^A, g^A, S(t), D^B(t), D^C(t))) \quad (23)$$

Determine a decision $D^A(t)=g_0^A(\xi_t^A)$, under conditions:

$$D^A(t) \in \Delta^A(t),\ S(t) \in \boldsymbol{X},\ D^B(t) \in \Delta^B(t),\ D^C(t) \in \Delta^C(t)$$

b) Observation of battle state Ξ_t at the following moments $t+\eta, t+2\eta, \ldots$

$$\text{If } \Delta S(t+n^*\eta) \geq \Delta^{gr}S(t+n^*\eta)\text{, then } t := t + n^*\eta \quad (24)$$

where

$$\Delta S(t+n\eta) = \left(\sum_{m=1}^{|X|}\left|S_m(t+n\eta) - S_m^{DA}(t+n\eta)\right|^p\right)^{\frac{1}{p}},\ p \geq 1\text{, for p} = \infty,\ \Delta S(t+n\eta) = \max_{m=1,\ldots,|X|}\left|S_m(t+n\eta) - S_m^{DA}(t+n\eta)\right|,$$

go to stage 1

The multiple criteria formulation:

$$\chi^A(t, T^A, g^A, s, D^B(t), D^C(t)) = (\tilde{f}_1, \tilde{f}_2, \tilde{f}_3, \tilde{f}_4), \quad (25)$$
where
$$\tilde{f}_1 = \inf\{f_1 : P\{F_1(t, T^A, g^A(\Xi_t\ ), S(t), D^B(t), D^C(t)) \leq f_1 \mid S(t) = s\} \geq q_1,$$
and $P\{F_1(t, T^A, g^A(\Xi_t^A), S(t), D^B(t), D^C(t)) \geq f_1 \mid S(t) = s\} \geq 1 - q_1\}$,
$$\tilde{f}_2 = \inf\{f_2 : P\{F_2(t, T^A, g^A(\Xi_t\ ), S(t\ ), D^B(t), D^C(t)) \leq f_2 \mid S(t) = s\} \geq q_2,$$

$$\text{and } P\{F_2(t,T^A,g^A(\Xi_t^A),S(t),D^B(t),D^C(t)) \geq f_2 \mid S(t)=s\} \geq 1-q_2\}$$
$$\widetilde{f}_3 = \inf\{f_3 : P\{F_3(t,T^A,g^A(\Xi_t),S(t),D^B(t),D^C(t)) \leq f_3 \mid S(t)=s\} \geq q_3,$$
$$\text{and } P\{F_3(t,T^A,g^A(\Xi_t^A),S(t),D^B(t),D^C(t)) \geq f_3 \mid S(t)=s\} \geq 1-q_3\}$$
$$\widetilde{f}_4 = \inf\{f_4 : P\{F_4(t,T^A,g^A(\Xi_t\ ),S(t),D^B(t),D^C(t)) \leq f_4 \mid S(t)=s\} \geq q_4,$$
$$\text{and } P\{F_4(t,T^A,g^A(\Xi_t^A),S(t),D^B(t),D^C(t)) \geq f_4 \mid S(t)=s\} \geq 1-q_4\},$$

$S(t) \in \mathbf{X},\ q_1,q_2,q_3,q_4 \in \mathbf{Q^A}$ are given,

if ξ_t realisation of Ξ_t , then

$D^A(t) = g^A(\xi_t)$

Stage 1. An observation Ξ_t (the distribution: $F(\xi_t^A / S(t), D^B(t), D^C(t))$ is determined),

Stage 2.

Find the decision function $g^{A*} \in G_N^{A\leq}$, which belongs to non-dominated set of decision functions:

$$G_N^{A\leq} = \chi^{-1}(Y_N^{G^A\leq}), \tag{26}$$
$$\text{where } Y_N^{G^A\leq} = \{y \in Y_{\max}^{X\times\Delta^B(t)\times\Delta^C(t)} \mid \neg\exists_{z\in Y_{\max}^{X\times\Delta^B(t)\times\Delta^C(t)}} z \leq y\},$$
and
$$Y_{\max}^{X\times\Delta^B(t)\times\Delta^C(t)} = \{y \in C \mid y_i = \max_{X\times\Delta^B(t)\times\Delta^C(t)}(\widetilde{f}_i)\},$$
$$\text{where}: \widetilde{f}_i \text{ like } (2.26), i=1,\ldots,4$$
$$C = \{y \in R^3 \times \{0,1\} \mid y = (\widetilde{f}_1,\widetilde{f}_2,\widetilde{f}_3,\widetilde{f}_4)\}$$

Determine a decision $D^A(t)=g^{A*}(\xi_t^A)$, where $g^{A*} \in G_N^{A\leq}$

b) The same operations like in the previous formulation (24).

To solve the problem the simulation method is proposed. It is very important to have a possibility of stochastic process (10) trajectory generation. The parameters of the decision model are estimated during the simulation process. The entrants in the interactive mode during the game determine some of them. The replications of the simulation game many times with the same initial scenario enable the estimation of characteristics of combat process. The formal models of decision and combat process allow the correct analysis of simulations. To estimate the results of local combats we propose the specific models of the situations. These models were implemented in a simulation environment. The construction of the decision model requires the distribution of the simulation execution. Especially three different decision centres are located in different places. The decisions are carried out on the basis of initial scenario, received from main centre, which can represent peacekeeping forces, and then the “common model” is executed. The decision-makers can update their decisions during the simulation running (interaction process), taking into account the previous decisions and observed situation. The reconnaissance model, which is simulated, reflects the possibility of observation for each side. Each of the orders and reports are presented in real CIS (Command Information System) – in Polish system there are in ADatP3 format.

THE ENVIRONMENT FOR COMBAT INTERACTIVE SIMULATION

Federation Design

A generalized process for building HLA federations can be described by FEDEP – a high-level framework for the development and execution of HLA federations. According to FEDEP, we should determine which existing simulation systems are suitable to become members of the federation. But often federates don't exist and we have to develop all federation members. New federates or changes to the existed software design and implementation must be implemented. Using RUP (Rational Unified Process), Rose (a graphical component for modelling and development) and UML a object oriented representation of the federation can be developed: the specification of object classes, attributes, methods, object relationships, interaction classes, and parameters.

The base software package layer of the MSCombat is composed of control package, RTI package, scenario generator package, combat models package and other. The detailed project of The MSCombat contains a set of class diagrams (with attributes, methods and relationships), a set of sequence diagrams, a set of component diagrams and a deployment diagram. For instance Fig. 1. presents the MSCombat software package layer and class diagram of the simulation time manager.

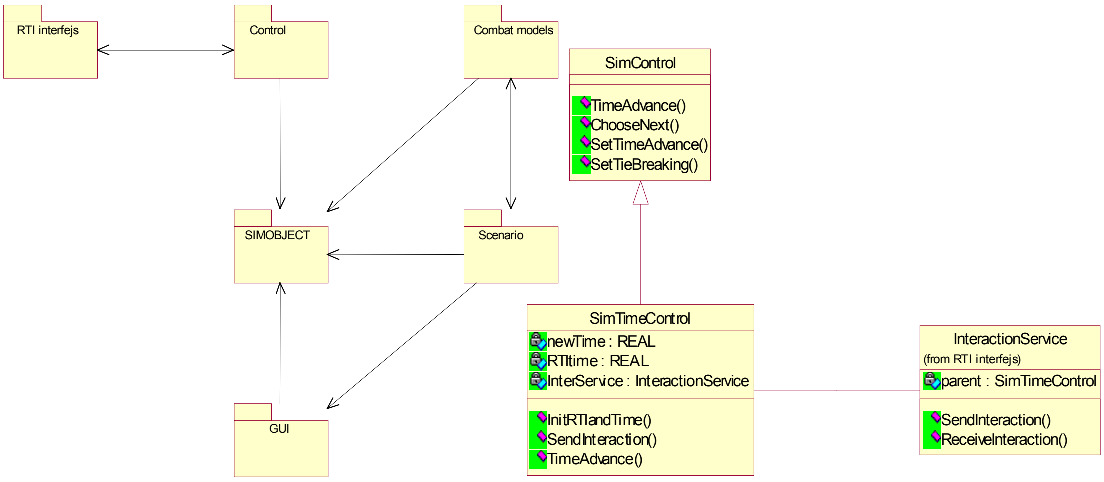


Figure 1: The MSCombat Software Package Layer and an Example of Class Diagram.

During this phase we should allocate the entities and actions from the federation conceptual model to the federates. Moreover technical issues such as time management, federation management can be described at this phase too. In the MSCombat environment a conservative mechanism is implemented but time-step, hybrid or real-time algorithm can be realized in the interactive mode. The RTI software controls global "time flow" and global message ordering.

Federation Development

Main tasks at the current phase is to develop the Federation Object Model (FOM), implement or modify existing federates and prepare the federation for integration and test. In order to create FOM model we can use Object Model Development Tool which provides integrated access to supporting resources and automates the production of the Federation Execution Data (FED) file required by the RTI. The interoperability of MSCombat system is determined by the interactions and objects classes included in FOM file "MSCombat.fed". Each object or interaction class must be represented by adequate class with attributes and methods in a project and then in a software. Rational Rose provides a proprietary scripting

language (Rose script) which allows for the importing and exporting of object models. In order to export an OMDT model to Rational Rose we should to:

1) Prepare a FOM model using OMDT.
2) Generate and export the Rose script file (*.ebs).
3) Open the script file in the Rational Rose.
4) Execute that script.
5) Results: several new classes will be added to the current Rose model.

The FOM components that will be exported to the Rose model are classes, attributes, interactions, and parameters. The Rose script rules are:

- the created classes consist of FOM attributes as public;
- interactions are treated differently than attributes – interactions are created as public methods of a class called HLA Interactions, because there are no classes with interactions in the HLA object model.

The methods of the HLA Interactions then should be divided and included into the existing or new the project classes. A class diagram generated from “MSCombat.fed” with described method is presented in Fig. 2.

Figure 2: MSCombat FOM Class Diagram.

The visualization federate was constructed in order to virtual reconnaissance. Its SOM is based on the Aggregate object while other constructive federates use the Unit object and mentioned interactions.

The FOM of a prototype MSCombat has been extended to more complex model which is partly consistent with the DiMuNDS federation object model. A compatibility is achieved on the object, attribute, interaction, parameter name, data type and meaning levels. For example, a part of object classes from a professional simulation system is:

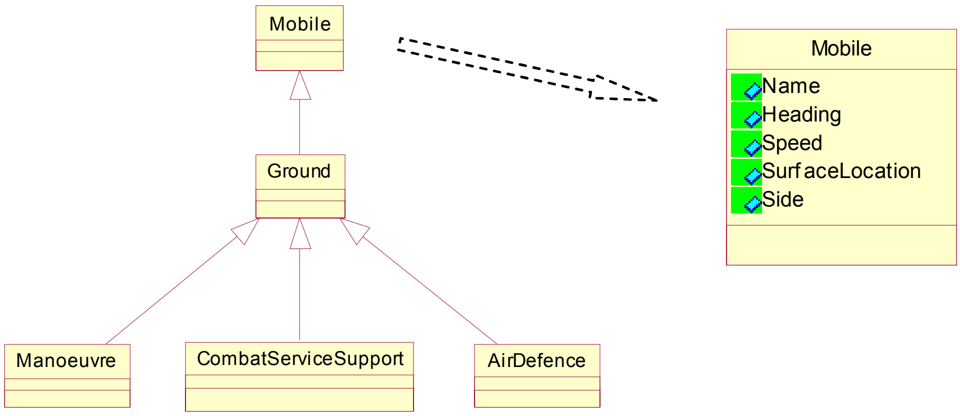
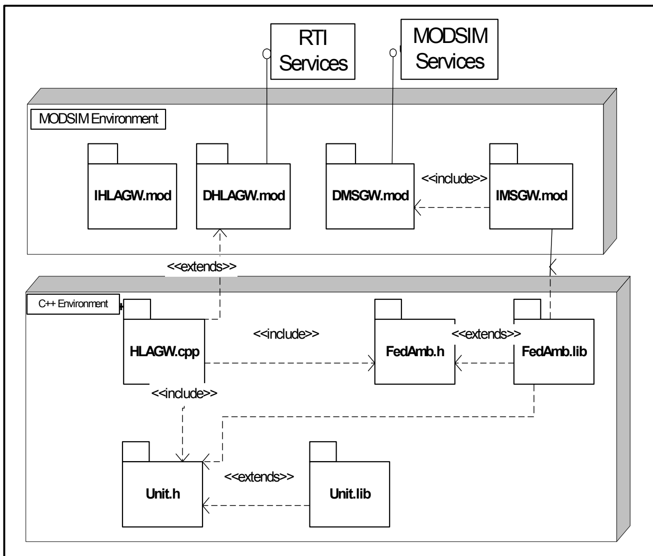


Figure 3: A Part of Extended FOM.

The second task of the phase “Develop Federation” is to implement or modify existing federate software. The MSCombat is build with object-oriented simulation language MODSIM/SIMOBJECT and RTI/HLA API library. The cooperation between Runtime Infrastructure and MODSIM is realized with specific interface, that is built in MSVisual C++ and appended to MODSIM. The interface is composed of many software components, which have to interact according to services called by a user or a program. The functionality of the interface is limited by the set of chosen RTI services to implementation in MODSIM. The most important services implemented as procedures and object methods are listed in Fig. 4.




```
FedAmbObj = OBJECT
ASK METHOD ReceiveInteraction(IN interaction:
STRING; IN message: STRING; IN unitName: STRING;
IN side: STRING; IN xPosition: STRING; IN yPosition:
STRING; IN item: STRING; IN state: STRING; IN time:
REAL);
ASK METHOD ReflectAttributeValue(IN objHandle:
INTEGER; IN attrHandle: INTEGER; IN attrValue:
STRING; IN time: REAL);
ASK METHOD DiscoverObjectInstance(IN objHandle:
INTEGER)
ASK METHOD TurnInteractionOn(IN interaction:
STRING);
ASK METHOD TurnInteractionOff(IN interaction:
STRING);
ASK METHOD ProvideAttributeUpdate(IN objHandle:
INTEGER; IN attrHandle: INTEGER);
……...
END OBJECT;
```

Figure 4: Modsim – HLA Interface.

Federation Integration and Testing

This phase consist of followed tasks:

- Plan the federation execution;
- Establish all required interconnectivity between federates;
- Test federation prior to execution.

There are three levels of testing: federate testing, integration testing and federation testing. In order to finalize this phase we propose the following steps:

- Battle scenario preparing;
- Simulation environment configuration;
- Initial condition input and choosing combat model version;
- Setting monitors of internal and external characteristics;
- Experimentation – battle simulation in a interactive mode;
- Experiment repetition with new models and condition data.
- Analysis results of the experiment series;

We can distinguish two kinds of characteristics: external and internal. The external characteristics derive from modelling process and describe the commander decision process, combat process and other simulation result. The most important characteristics there are: the difference of mission time realisation and mission complete planned on the higher level, the losses after the completion of mission, the degree of the mission completion, the possibility of actions at a moment t. One of specific indicators – combat success indicator:

$$BT(t) = \frac{F_2^A(t)/F_0^A(t)}{F_2^B(t)/F_0^B(t)}$$

where $F_2^A(t)$, $F_2^B(t)$ – the losses of two sides at the moment t and $F_0^A(t)$, $F_0^B(t)$ – combat value of the sides' forces. It is possible to find three situations:

- If $BT(t) < 1$, then side A is winning,
- If $BT(t) = 1$,then balance of the battle at the moment t,
- If $BT(t) > 1$, then side B is winning.

The internal characteristics describe environment performance, service failures, resource usage, workload etc. The most important characteristics there are: two-way latency of TSO interaction sending and receiving, two-way latency of attribute update, latency of ownership acquisition, maximum number of object instance, initialisation time of the whole system. The goal of this benchmark is to provide a general-purpose method to gather latency and throughput performance data for the largest possible number of RTI configurations. The independent variables are: number of objects instances, number of attribute types, object attributes an interaction parameters size, processor clock and available RAM. An example of a test sequence diagram is presented in the Fig. 5.

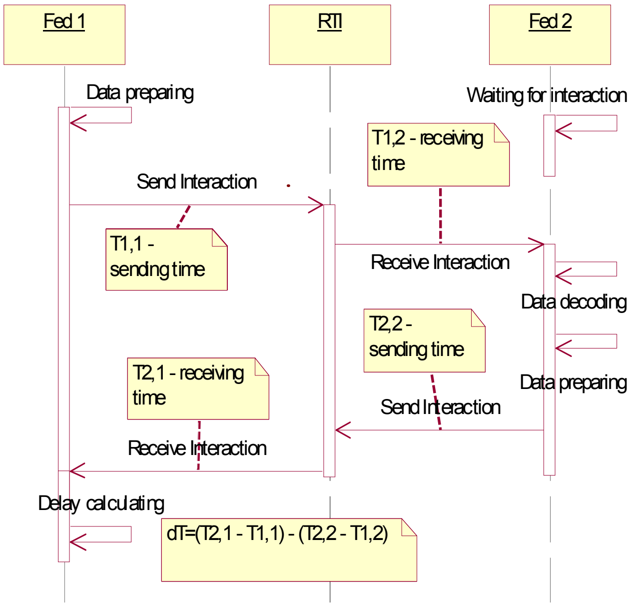


Figure 5: Interaction Latency Test Sequence Diagram.

Execute Federation and Prepare Results

The last phase of The FEDEP is concerned with:

- Execute the federation;
- Process the output data from federation execution;
- Report results;
- Archive reusable federation products.

The deployment diagram of the MSCombat environment is presented on the Fig. 6.

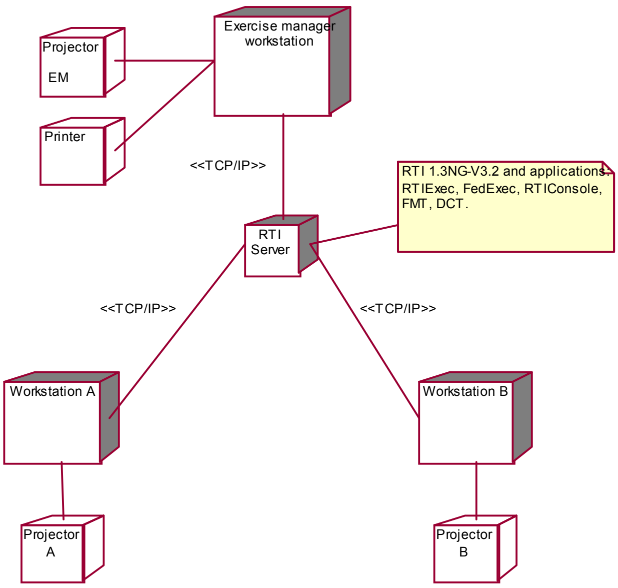


Figure 6: Deployment Diagram of the MSCombat Environment.

An extended version of MSCombat is a professional simulation system environment. It includes:

- a data base server,
- an application server,
- a few sets of terminals (each set for one conflict side),
- a 3D visualization station.

Statistical measures and other data reduction methods are used to transform raw data into derived results. We have used commercial off-the-shelf (COTS) statistical analysis tools SPSS. At the execution phase we have run stand-alone tests on our federate based on two implementations of RTI: DMSO RTI NG 1.3 and commercially available Pitch RTI. It is RTI performance in terms of the rate at which time advance requests are processed. The presented results were obtained in LAN environment. A few instances of the program (the time-regulating and time-constrained federate) were run on local PC (PC 700-2000 MHz, 128-512 MB RAM, Win2000). Each instance was responsible for sending and requesting a the specified number of interactions and collecting statistics on performance.

The example of internal characteristics "The maximum number of object instance" is presented in the Tab. 1 and Fig. 7.

Table 1: Outcomes from Test "The Maximum Number of Object Instance".

# Attributes	# instances (RTI: 256 MB – federate: 128 MB)	# instances (RTI: 256 MB – federate: 256 MB)	# instances (RTI: 128 MB – federate: 256 MB)
1	65536	65536	65536
10	65536	65536	65536
20	60292	61092	63567
30	40423	43025	23301
40	29838	31878	–
50	25135	26126	–
100	13057	13246	15356

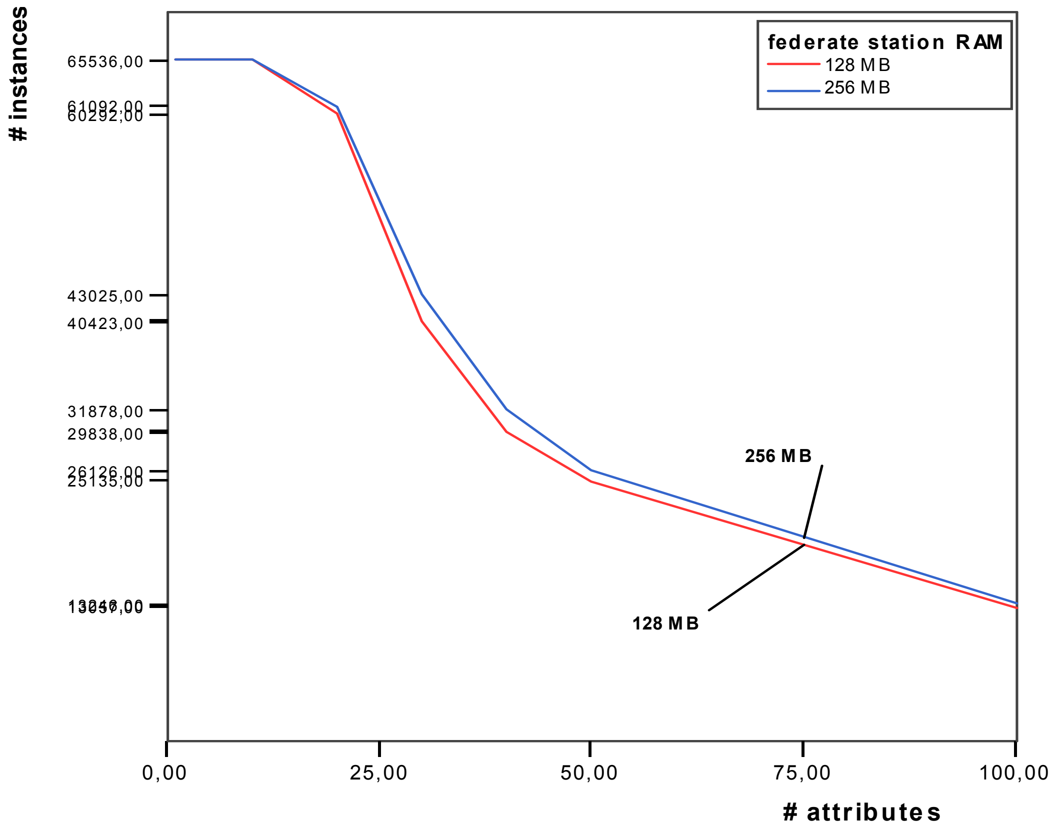


Figure 7: Outcomes from Test "The Maximum Number of Object Instance".

The example of external characteristics "The losses after the completion of mission" is presented in Fig. 8 – the estimation of Red losses can be presented with tendency function fitting.

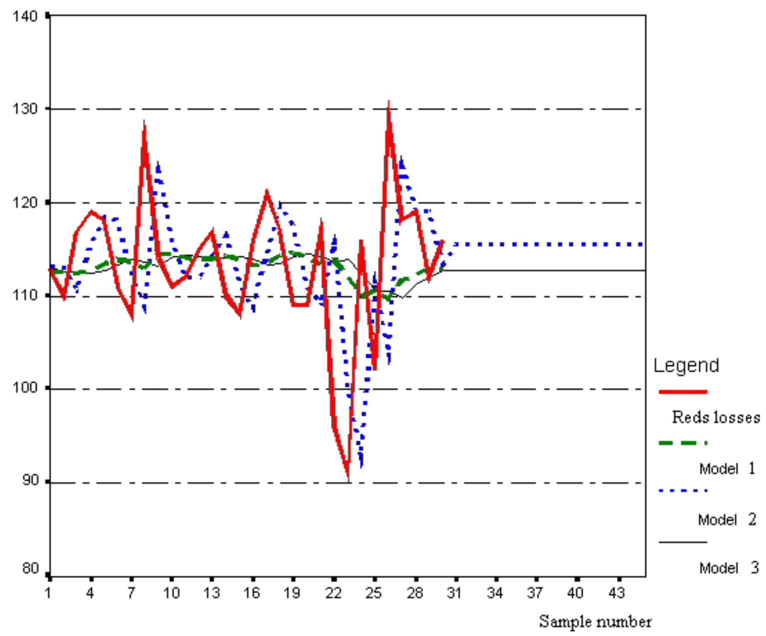


Figure 8: Tally for Trend Models of Red Losses.

CONCLUSIONS

MSCombat is the example of simulator which has been developed for different purposes, but can be used in new simulations thanks to HLA interface. Migration to HLA requires some modification to existing management and engineering processes to capture the benefits offered by HLA. We have verified a development cycle with RUP, UML and FEDEP. We have to make extensive modifications to adapt the simulator so that it can be integrated into a new combined simulation. The performance of the environment with MODSIM/HLA interface is comparable with performance of base RTI environment in the focus of proposed characteristics. The benchmark results are intended to provide assistance to simulator developers in the whole process of HLA federation design, implementation and execution.

The environment proposed is built as an opened system and can be developed and improved – that means there is easy way to include new combat models, unit structures, tactical rules and more monitored characteristics. The characteristics of battle process are being monitored during the simulation process and their statistical analysis allows combat actions predicting for different conflict situations. It should be stressed that approach proposed here requires good knowledge of conflict processes and careful preparation of a conflict scenario. The validation process is very difficult but it is possible to use description of known conflicts and compare with the simulation results. The very interesting direction of further researches there is pattern recognition of decision situation on the basis of simulated actions for example our local combat generator there is something like knowledge base. We try to use virtual reality tools to realize one of important element of combat planning there is reconnaissance of battlefield by commander before the battle.

The important aspects there are financial conditions of the simulation system development. Our experiences indicate one of interesting ways of the realization process by prototype of the system development. MSCombat, which was modelled, designed and developed in our University enabled proper preparation of concept phase and took place in the formal competition, announced by Department of Armament Policy (part of MoD) and finally we have won the project realization.

ACKNOWLEDGEMENTS

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POLISH FEDERATION OF LAND BATTLE IN A DISTRIBUTED INTERACTIVE ENVIRONMENT

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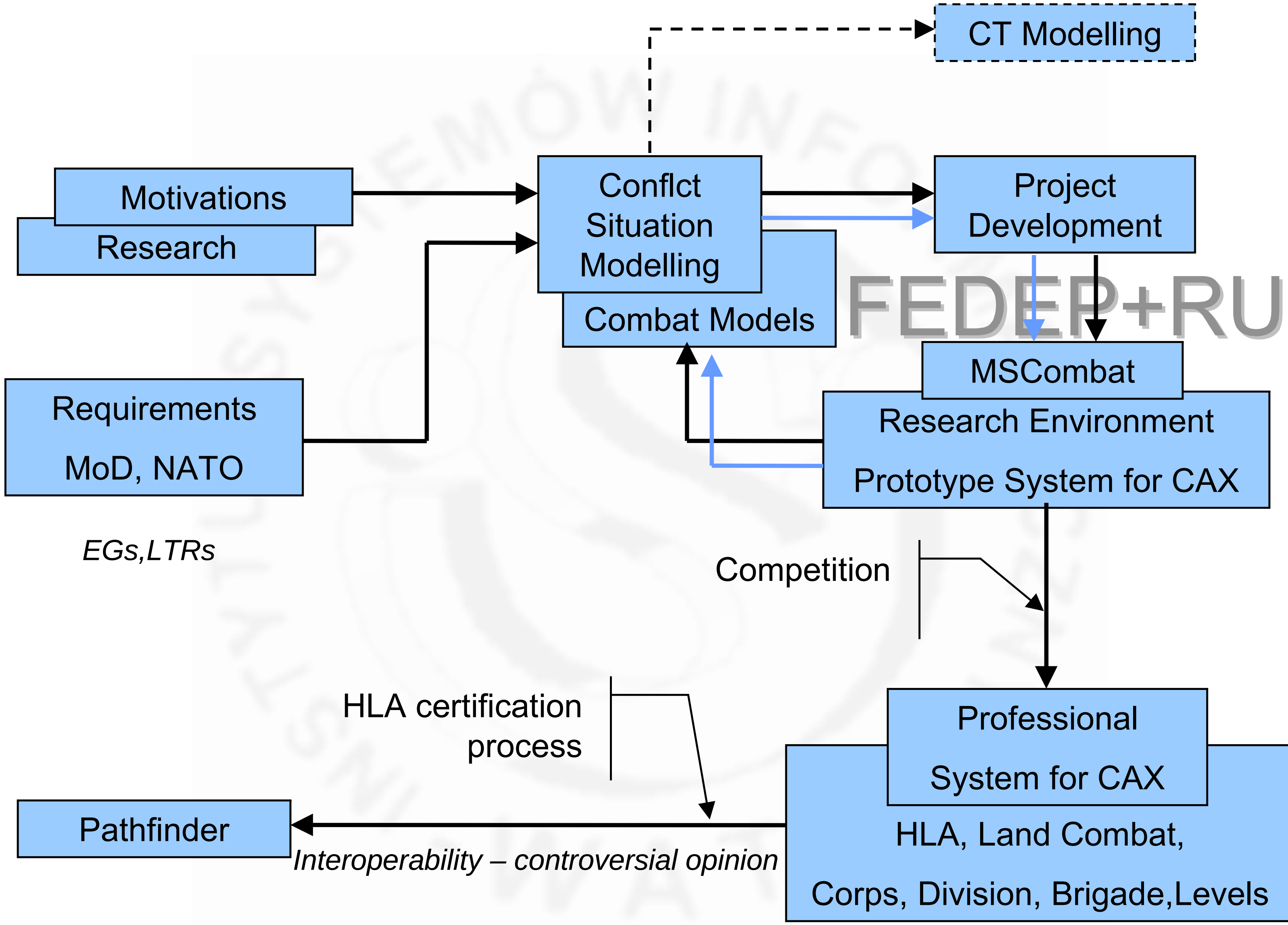
OUTLINE

- APPROACH
- THE RESEARCH PROBLEMS
- MODELLING
- SIMULATION GAME ENVIRONMENT
- TESTING METHOD
- RESULTS ANALYSIS
- CONCLUSIONS

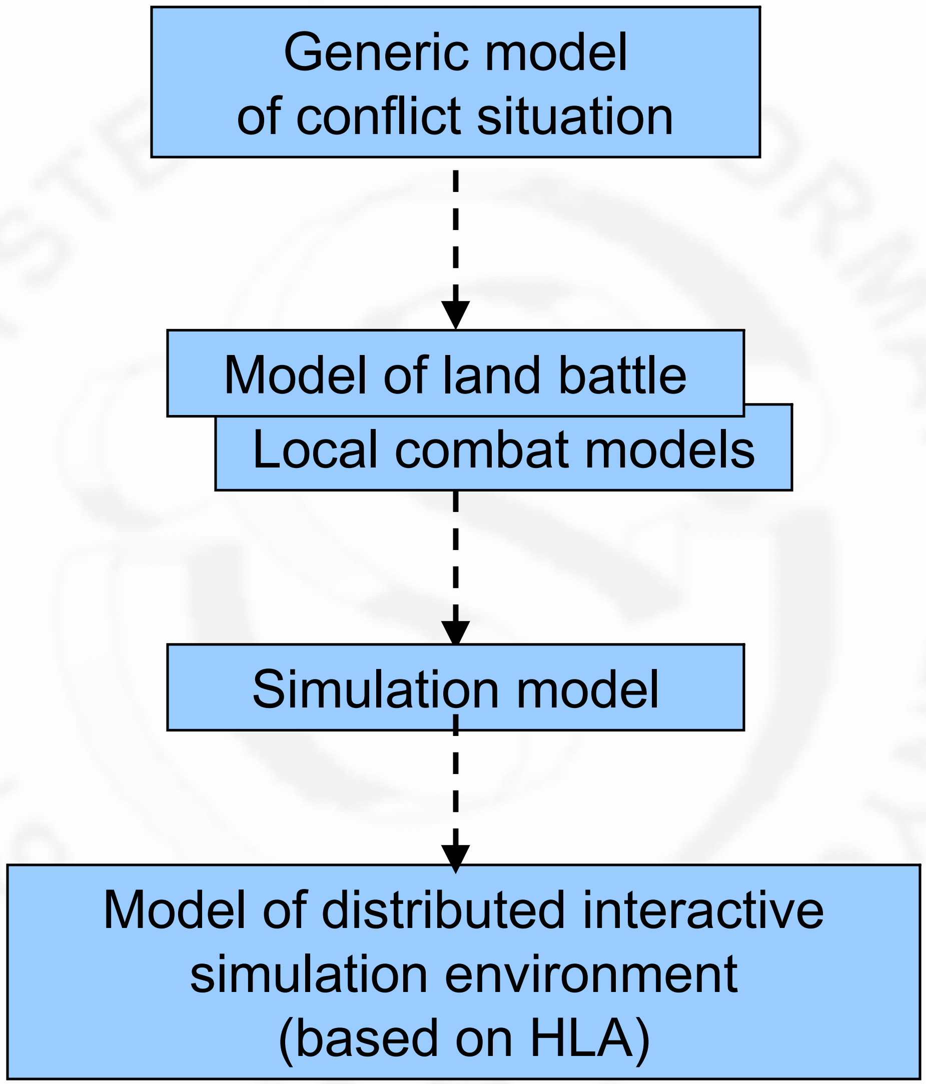
General view



The research problems

- How to reflect the real conflict situation?
- How to determine the best decisions?
- What type of criteria should we take into account?
- What a sense do the decisions have under uncertainty conditions?
- How to decompose the complex situations into local type situations?
- What type of local conflict models should we use in the situation?
- Do any patterns of behaviour exist in a decision situation?
- How to reflect uncertainty and surprise in a conflict situation?
- How to show the dynamics and changes in a situation?

Models and relationships



Conflict situation (military)

Game theory approach:

$$\Gamma^{w} =< \{1,2,3,4\}, \{S_{k}^{w}\}_{k\in\{1,2,3,4\}}, \{H_{k}^{w}\}_{k\in\{1,3,4\}} >$$

- 1st and 3rd players represent opposite sides,
- 4th player - peacekeeping forces,
- 2nd player there is nature - battlefield
- S_k^w - kth player strategy,
- H_k^w - kth player payoff

$$H_k^w : S_1^w \times \Omega \times S_3^w \times S_4^w \to R,\ k = 1,3,4$$

$$d^k : \Phi_k \to S_k^w, \phi^k \in \Phi_k, s_k^w \in S_k^w, d^k(\phi^k) = s_k^w,\ k = 1,3,4$$

$$\tilde{h}_{q_k}^{w} = \inf\{h_{q_k}^{w} : P(H_k^w(g^1(\Xi_1), \Theta, g^3(\Xi_3), g^4(\Xi_4)) \le h_{q_k}^{w}) \le q_k \ i$$
$$P(H_k^w(g^1(\Xi_1), \Theta, g^3(\Xi_3), g^4(\Xi_4)) \ge h_{q_k}^{w}) \le 1 - q_k\}$$

$$\tilde{\Gamma}^{w} =< \{1,2,3,4\}, \{G_1, \Omega, G_3, G_4\}, \{\tilde{h}_{qk}^{w}\}_{k\in\{1,3,4\}} >$$

Simulation model of a conflict situation

- The conflict model is operational game represented as a triplet:

$$\Gamma_S = \langle U_G, M_{SW}, SC_W \rangle$$

where:

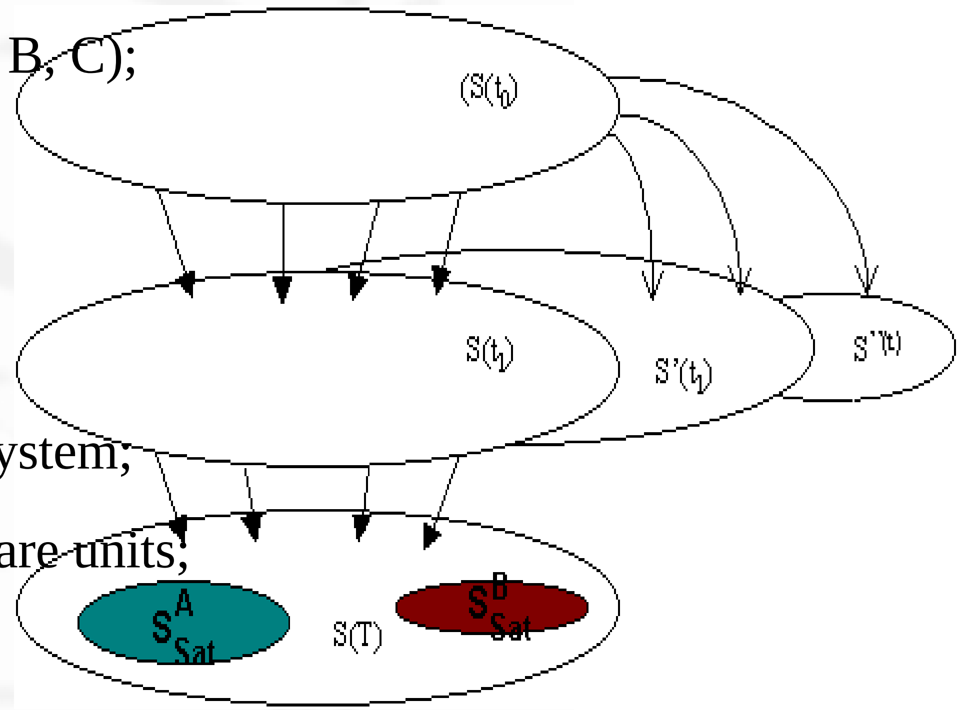
- U_G – game users' description
- M_{SW} – model of battle system
- SC_W – description of a conflict scenario

Model of Battle Process

$$\mathbf{S(t) = (S_{1Y}(t), S_{2Y}(t), S_{3Y}(t), S_{4Y}(t), S_{5Y}(t), S_{6Y}(t), S_{1PW}(t), S_{2PW}(t)),}$$

$$\mathbf{t \in [0,T], Y = A,B,C}$$

States of:



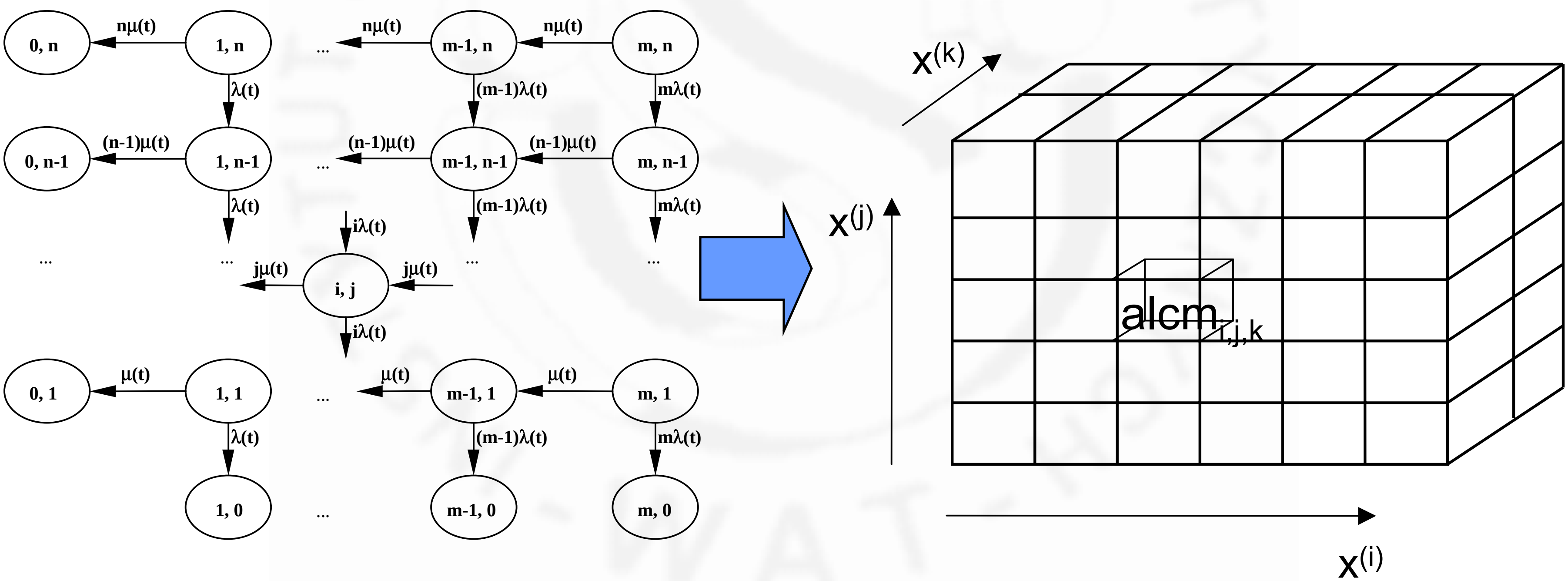
- $S_{1Y}(t)$ – land fighting units of side Y (A, B, C);
- $S_{2Y}(t)$ – supporting units of side Y;
- $S_{3Y}(t)$ – engineering units;
- $S_{4Y}(t)$ – logistics system;
- $S_{5Y}(t)$ – command and communication system;
- $S_{6Y}(t)$ – surveillance and electronic warfare units;
- $S_{1PW}(t)$ – terrain;
- $S_{2PW}(t)$ – weather, electromagnetic situation, pollution situation;

Aggregated Local Combat Model

Let introduce the specific matrix

$$ALCM = \left\lfloor alcm_{i,j,\dots,k} \right\rfloor_{I \times J \times \dots \times K}$$

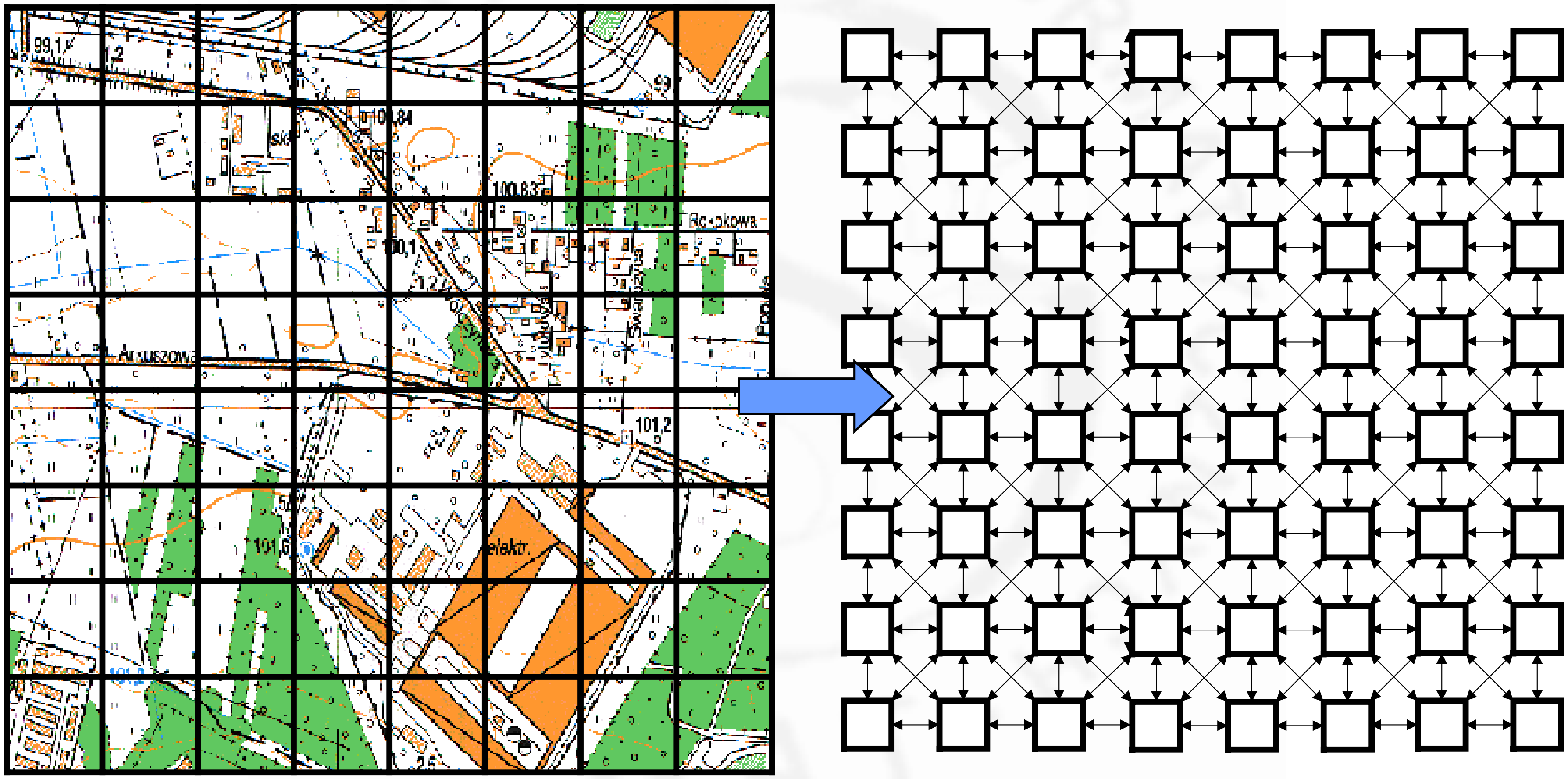
Where $alcm_{i,j,\dots,k}$ - is a vector of probability distributions (empirical) of output results



Poland

Modelling of decision process

- The terrain is considered as a discrete space (net Z)



Modelling of decision process

- Determination of tasks for sides (e.g. combat orders)
- Measurement of battle process state (surveillance subsystem)
- Choice of the decision function (algorithm), that minimise the maximum risk of decision-maker in the worst case (Bayesian risk in the case of partial knowledge)
- The decision determination - the trajectories of combat units and the fire allocation on the basis of chosen decision function (time difference, losses, degree of task realisation, readiness of combat units)

The decision model

Stage1. An observation Ξ_t (the distribution: $F(\xi_t^A / S(t), D^B(t), D^C(t))$ is determined),

Stage 2.

Find the decision function $g^{A*} \in G_N^{A\leq}$, which belongs to non-dominated set of decision functions:

$$G_N^{A\leq} = \chi^{-1}(Y_N^{G^A \leq}),$$

$$\text{where } Y_N^{G^A \leq} = \{y \in Y_{\max}^{X\times\Delta^B(t)\times\Delta^C(t)} \mid \neg\exists_{z\in Y_{\max}^{X\times\Delta^B(t)\times\Delta^C(t)}} z \leq y\},$$

and

$$Y_{\max}^{X\times\Delta^B(t)\times\Delta^C(t)} = \{y \in C \mid y_i = \max_{X\times\Delta^B(t)\times\Delta^C(t)}(\tilde{f}_i)\},$$

$$\text{where}: \tilde{f}_i \text{ like } (2.26), i = 1,\ldots,4$$

$$C = \{y \in R^3 \times \{0,1\} \mid y = (\tilde{f}_1, \tilde{f}_2, \tilde{f}_3, \tilde{f}_4)\}$$

Determine a decision $D^A(t) = g^{A*}(\xi_t^A)$, where $g^{A*} \in G_N^{A\leq}$

b) The same operations like in the previous formulation.

Distributed interactive simulation environment modelling

- The architecture of distributed interactive simulation environment is represented as the triplet:

$$DiS = < H, S, C>$$

where:

  - H – hardware architecture model,
  - S – software architecture model,
  - C –experiment configuration.

Distributed interactive simulation environment modelling

- Software architecture is represented as triplet:

$$S=<S^S, S^O, S^I>, \text{ where:}$$

  - S^S – communication and synchronisation part:
    - $S^S = < < W^S, \Gamma^S>, FW^S, \varnothing >$ (Berge graph)
  - S^O – object data part:
    - $S^O = < < W^S, \Gamma^O>, FW^O, FL^O>$, where for example:
      - $f^O{}_1 \in FW^O$: $<G^O{}_{SOM}, F^O{}_{SOM}, \varnothing>$ - is object data interface and:
        - $f^O{}_{SOM\ 1}(\bullet, id^O)$: $W^O{}_{SOM}(\bullet) \rightarrow W^A{}_{SOM}(\bullet, id^O)=\{a_i = <a\_name, a\_type, a\_size>\}$ – is set of attributes of object id^O;
        - $f^O{}_{SOM\ 2}(\bullet, id^O)$: $W^O{}_{SOM}(\bullet) \rightarrow \{P, S, PS, N\}$ – declaration of object data operations
    - $\forall\ id^O \in W^{OP}{}_{SOM}(\bullet)\ (f^O{}_{SOM\ 2}(\bullet, id^O)=P \vee f^O{}_{SOM\ 2}(\bullet, id^O)=PS)$ – publication constraint (the object id^O has to be „publish” or „publish and subscribe” in order to publish a data)
  - S^O –interaction data part (analogously):
    - $S^I = < < W^S, \Gamma^I>, FW^I, \varnothing>$

FEDEP

- „A high-level framework for the development and execution of HLA federations...”
- Step 4 of FEDEP (Develop Federation) consists of:
  - Develop FOM,
  - Establish Federation agreements,
  - Implement Federation modifications,
  - Implement all federate modifications
- FOM model and FED file generation
  → implementation of new federates
- Completness of step 4
- Conclusion: it should be completed, for example by RUP

The Rational Unified Process (RUP)

- RUP is a software engineering process, which provides a disciplined approach to assigning tasks and responsibilities within a development organization.

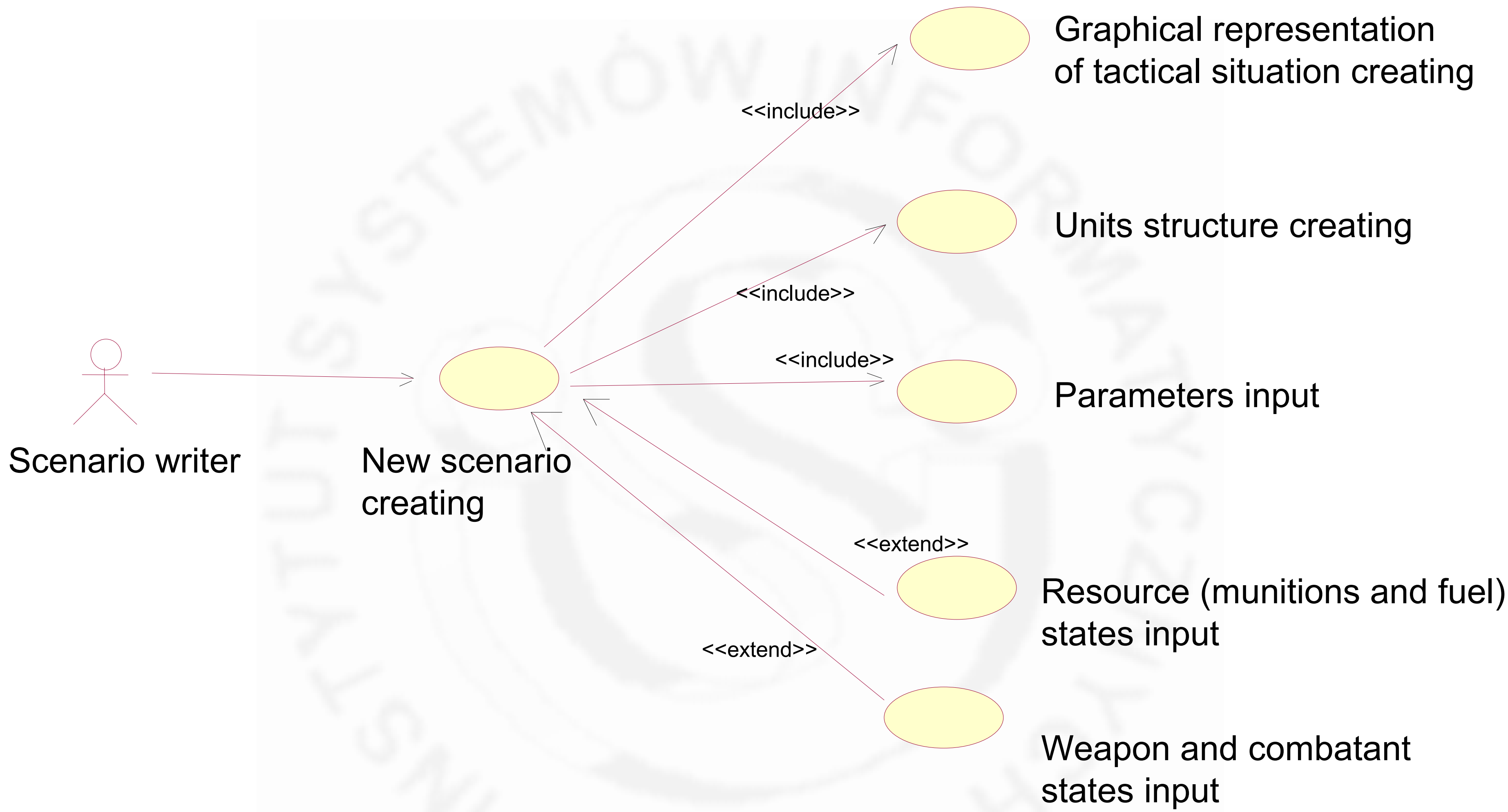
- Rose (a graphical component for modelling and development) and UML

↓

object oriented representation of federation

(object classes, attributes, methods, object relationships, interaction classes, and parameters).

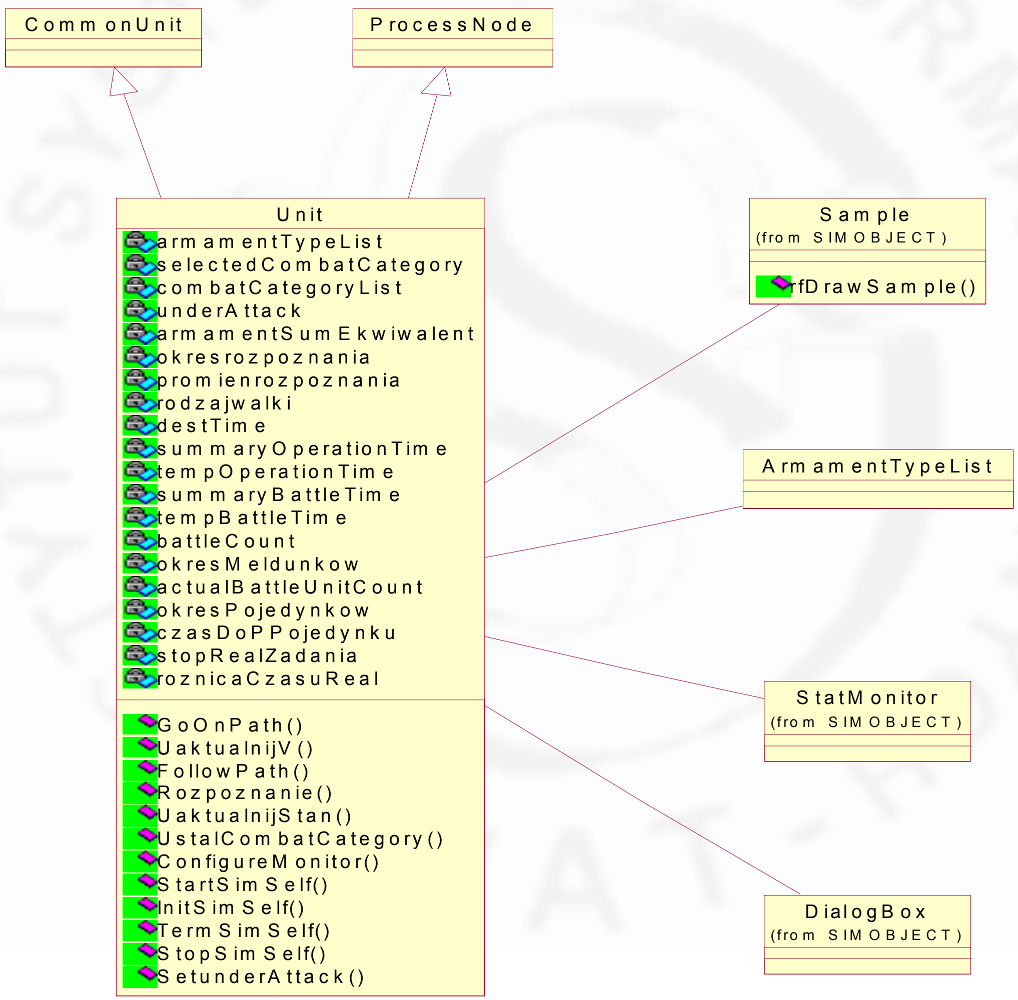
Use case view - Use cases



Example of Use case diagram (for „Scenario writer” actor)

Logical view - Federation Designing

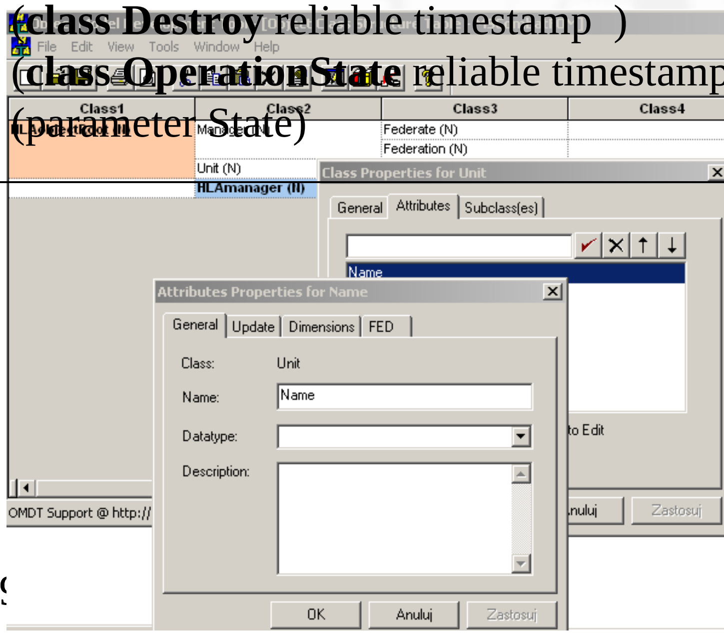
- Each element of the battle system , which represents one of the sides or the battlefield, can be represented as an object.



FOM Designing

(**class Communication** reliable timestamp
(parameter UnitName)
(parameter Side)
(parameter Message)
(parameter XPosition)
(parameter YPosition))
(**class Position** reliable timestamp)
(class ChangeState reliable timestamp
(parameter Item)
(parameter State))
(**class MovementState** reliable timestamp
(parameter State))
(**class Destroy** reliable timestamp)
(**class OperationState** reliable timestamp
(parameter State))

(**class Unit**
(attribute Name reliable timestamp)
(attribute Type reliable timestamp)
(attribute State reliable timestamp)
(attribute XPosition reliable timestamp)
(attribute YPosition reliable timestamp)
(attribute Side reliable timestamp)
)
(**class Aggregate**
(attribute Id reliable receive)
(attribute Side reliable receive)
(attribute ParentObjectId reliable receive)
(attribute Type reliable receive)
(attribute Coord reliable receive)
(attribute State reliable receive)
(attribute Rotation reliable receive)
(attribute Velocity reliable receive)
(attribute Destruct reliable receive)
(attribute Equipment reliable receive))



Example of Federation Object Model (from OMDT)

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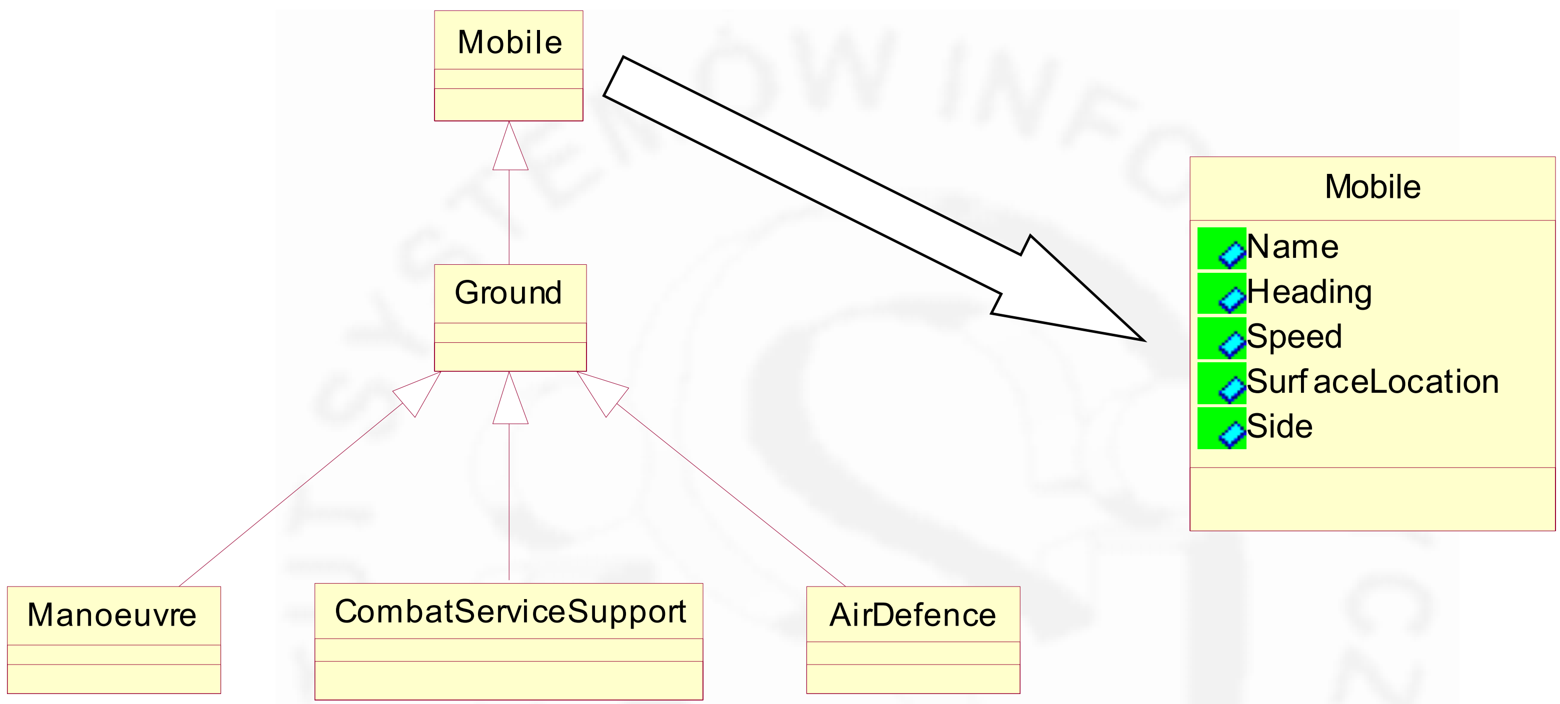
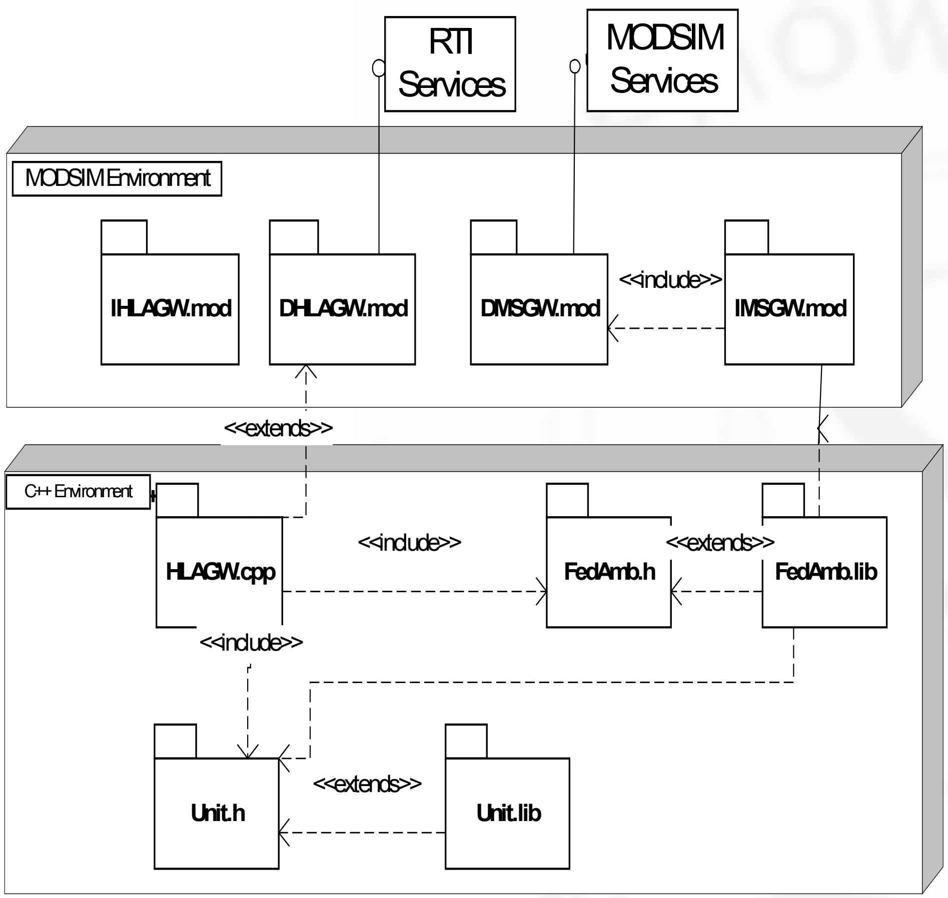
Logical view – extended FOM



A part of extended FOM (UML notation)

MSCombat – HLA interface



FedAmbObj = OBJECT

ASK METHOD ReceiveInteraction(IN interaction: STRING; IN message: STRING; IN unitName: STRING; IN side: STRING; IN xPosition: STRING; IN yPosition: STRING; IN item: STRING; IN state: STRING; IN time: REAL);

ASK METHOD ReflectAttributeValue(IN objHandle: INTEGER; IN attrHandle: INTEGER; IN attrValue: STRING; IN time: REAL);

ASK METHOD DiscoverObjectInstance(IN objHandle: INTEGER)

ASK METHOD TurnInteractionOn(IN interaction: STRING);

ASK METHOD TurnInteractionOff(IN interaction: STRING);

ASK METHOD ProvideAttributeUpdate(IN objHandle: INTEGER; IN attrHandle: INTEGER);

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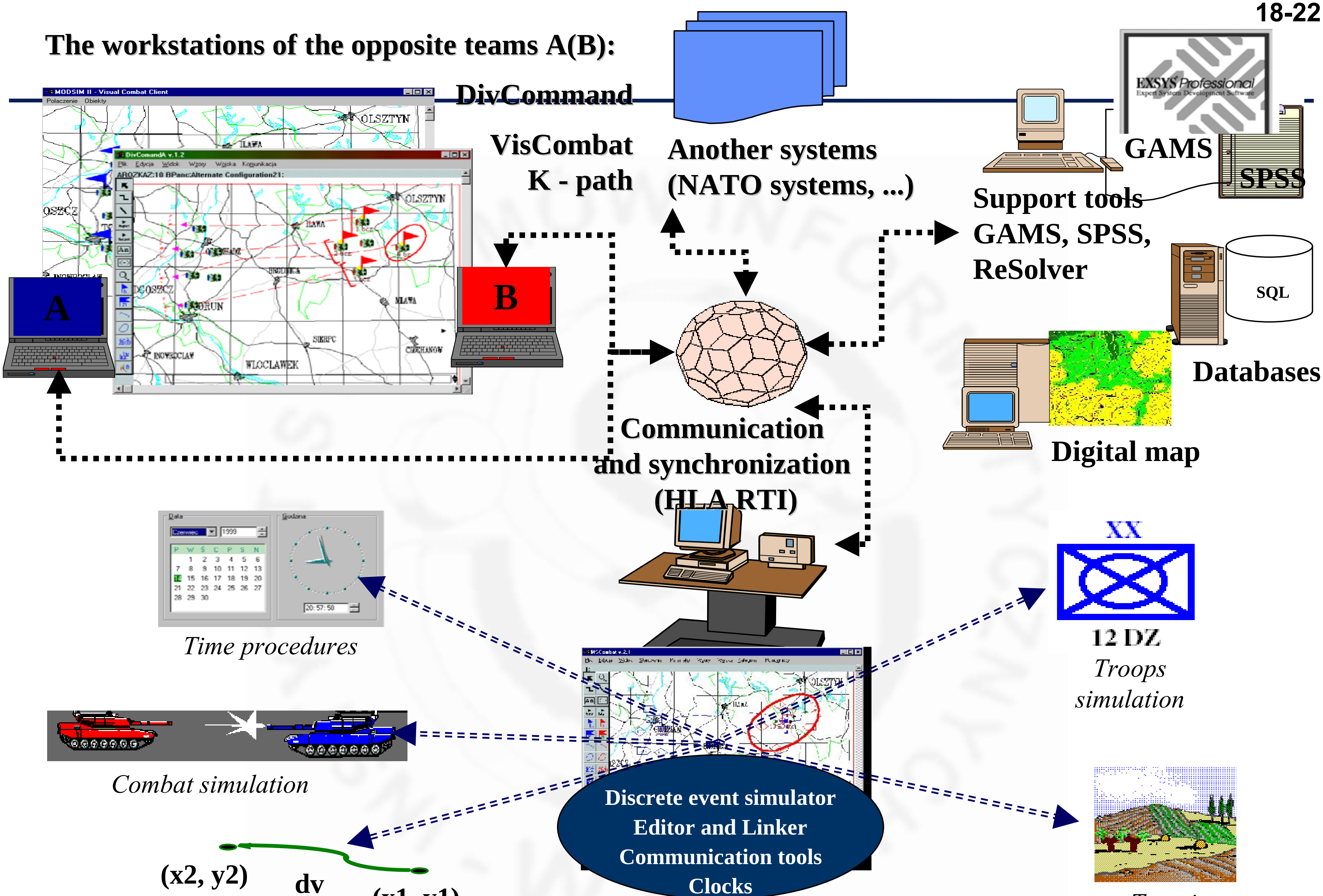
The workstations of the opposite teams A(B):



The application MSCombat
on the main station

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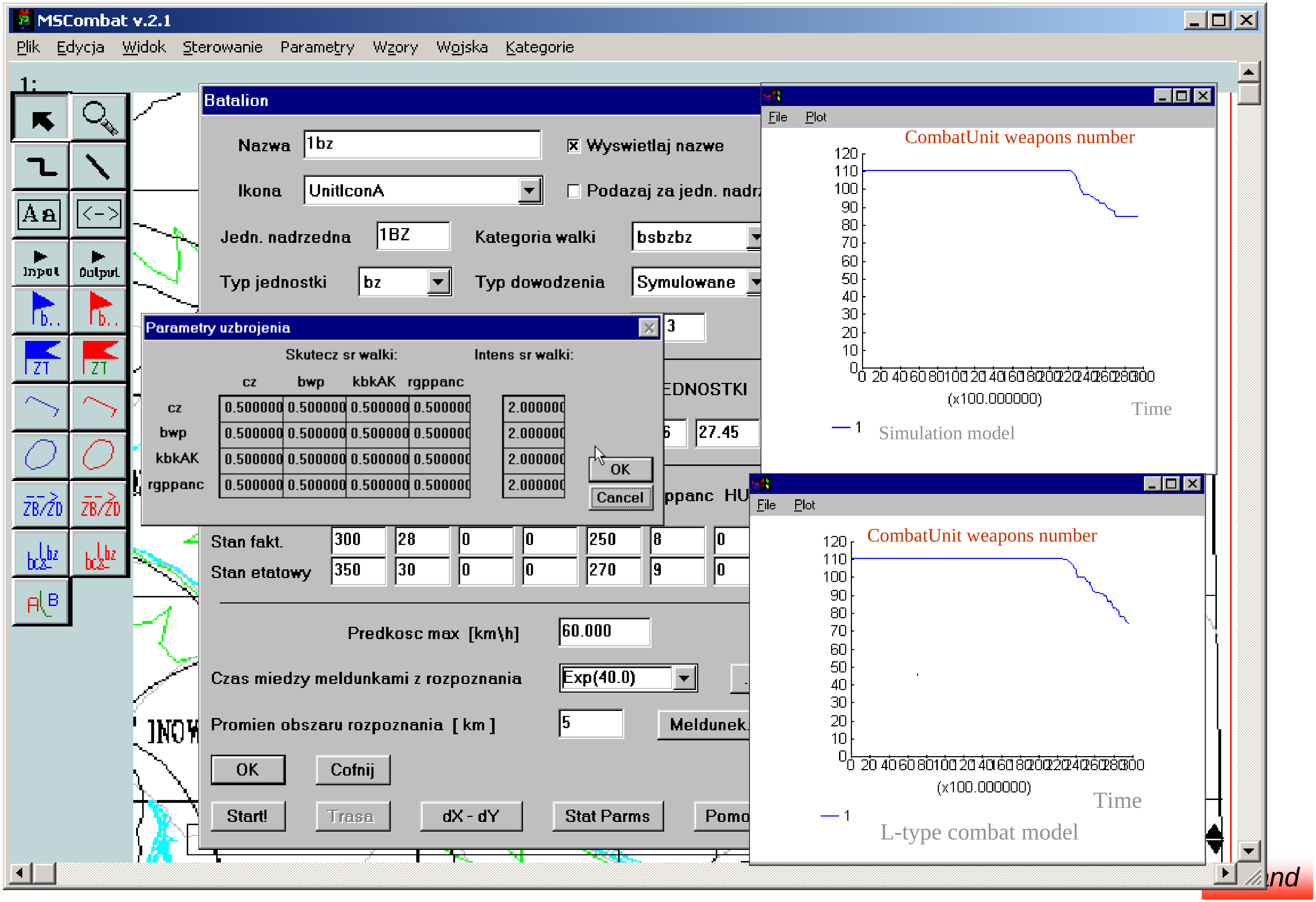
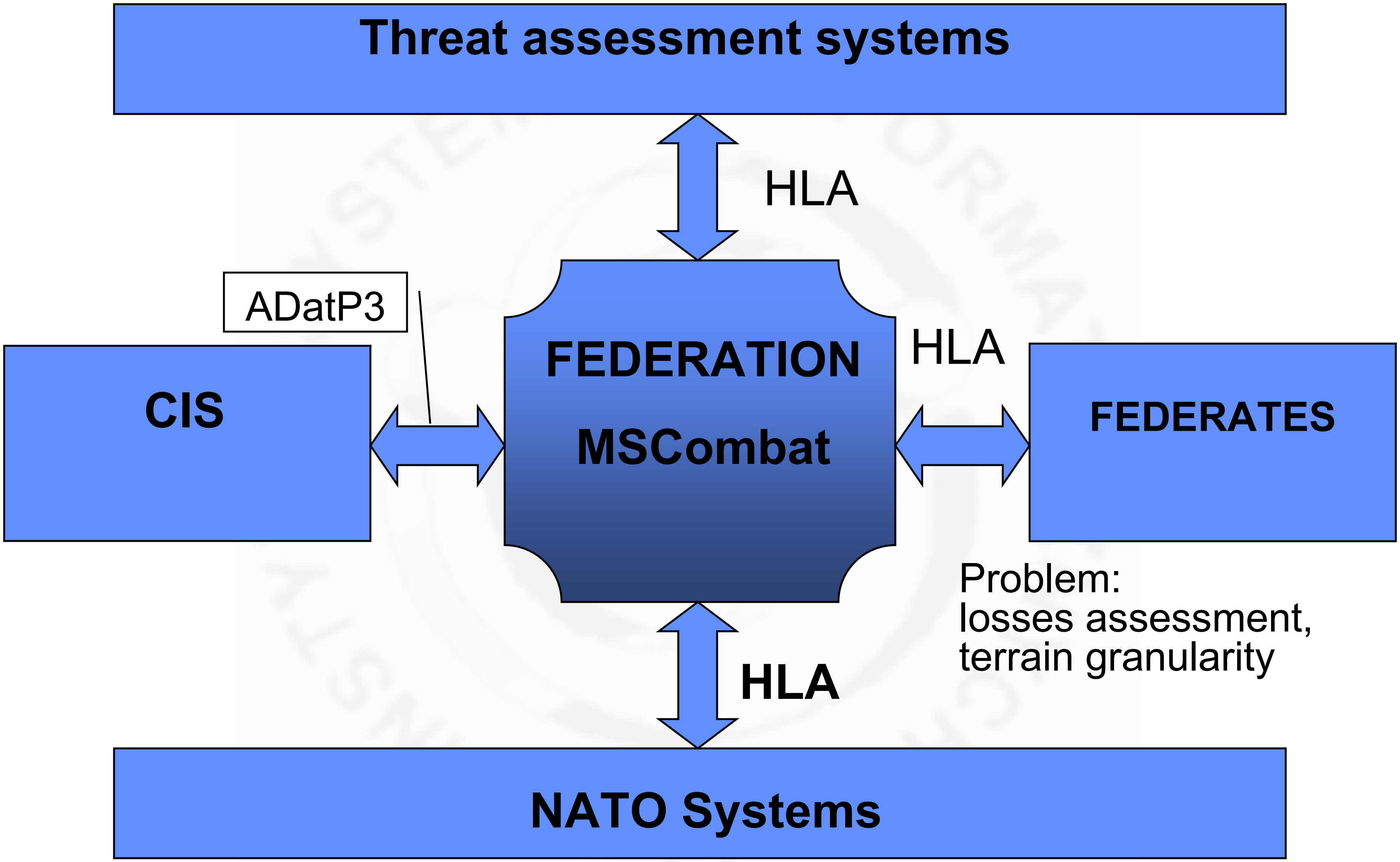
GUI


MSCombat v.2.1
Plik Edycja Widok Sterowanie Parametry Wzory Wojska Kategorie
Batalion
Nazwa 1bz
Wyswietlaj nazwe
Ikona UnitIconA
Podazaj za jedn. nadrz
Jedn. nadrzedna 1BZ
Kategoria walki bsbzbz
Typ jednostki bz
Typ dowodzenia Symulowane
Parametry uzbrojenia
Skutecz sr walki:
Intens sr walki:
cz bwp kbkAK rgppanc
OK
Cancel
Stan fakt. 300 28 0 0 250 8 0
Stan etatowy 350 30 0 0 270 9 0
Predkosc max [km\h] 60.000
Czas miedzy meldunkami z rozpoznania Exp(40.0)
Promien obszaru rozpoznania [km] 5
Meldunek
OK Cofnij
Start! Trasa dX - dY Stat Parms
CombatUnit weapons number
Time
Simulation model
CombatUnit weapons number
Time
L-type combat model

Interoperability

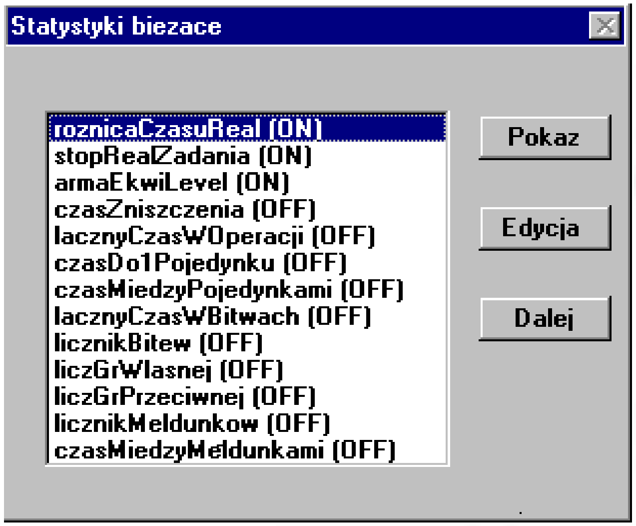


Testing – the characteristics

- External characteristics:
  - F_1 – the difference of mission time realization and mission complete planned on the higher level;
  - F_2 – the losses after the completion of mission;
  - F_3 – the degree of the mission completion.

    For example, it could be relative distance between final location of forces and required location or relative difference of final losses and required.
  - F_4 – the possibility of actions at the moment t.
- Internal characteristics:
  - Z_1 – The time of the decision support procedure realization,
  - Z_2 – Initialization time of federate,
  - Z_3 – The maximum number of object instances,
  - Z_4 – The initialization time of the whole system,
  - Z_5 – The time advance request rate,
  - Z_6 – The attribute update latency

External characteristics



$$BT(t) = \frac{F_2^A(t)/F_0^A(t)}{F_2^B(t)/F_0^B(t)}$$

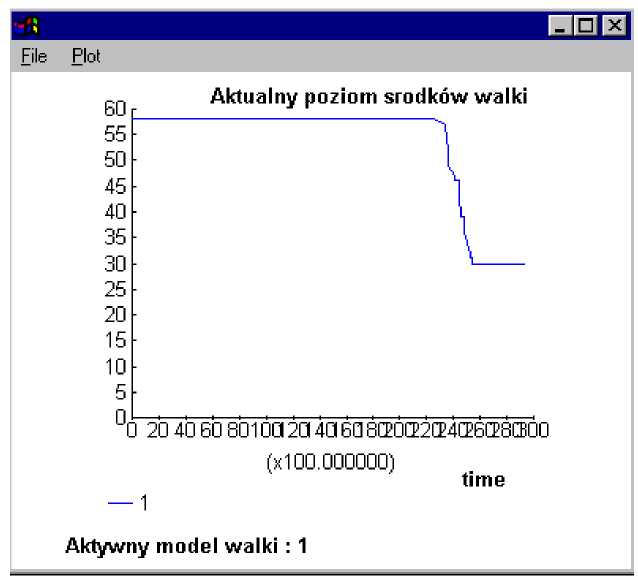
where $F_2^A(t)$, $F_2^B(t)$ – the losses of two sides at the moment t and $F_0^A(t)$, $F_0^B(t)$ – combat value of the sides' forces.

It is possible to find three situations:

- If $BT(t) < 1$, then side A is winning,
- If $BT(t) = 1$,then balance of the battle at the moment t
- If $BT(t) > 1$, then side B is winning.

Table 1. The simulation results

		$\frac{F_1^A(T^A)}{F_0^A(T^A)}$	$\frac{F_1^B(T^B)}{F_0^B(T^B)}$	$BT(T^A)$
N	Valid	30	30	30
	Missing	0	0	0
Mean		,1954	,3595	,5468
Median		,1971	,3641	,5500
Mode		,21	,38	,48
Standard deviation		1,545E-02	,03278	,05395
Variance		2,387E-04	,001074	,002911
Range		,08	,16	,23
Minimum		,16	,27	,44
Maximum		,24	,43	,67
Percentile	5%	,1672	,2797	,4472
	20%	,1799	,3406	,5061
	60%	,2003	,3706	,5660
	90%	,2101	,3920	,6146



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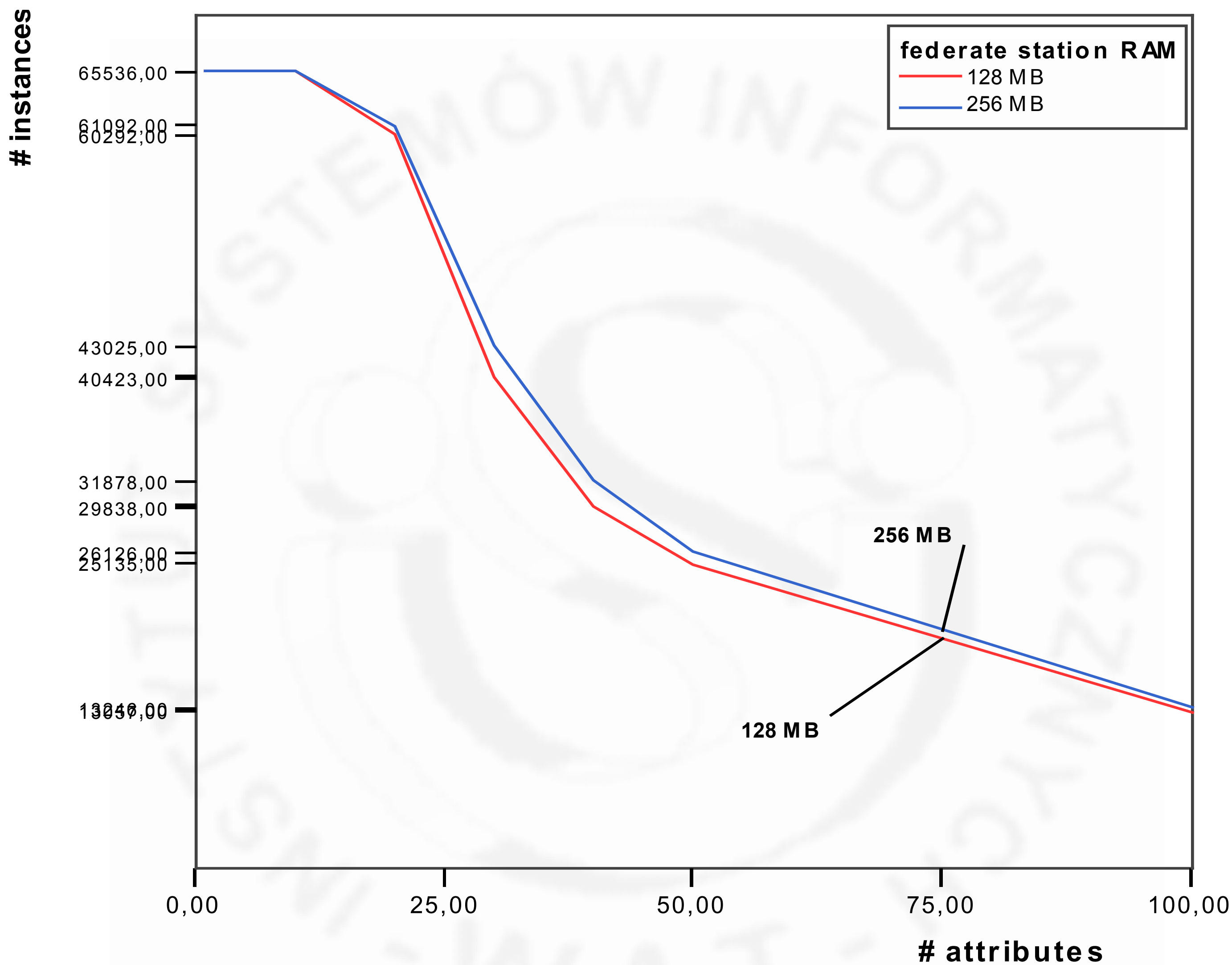
Internal characteristics

# Attributes	# instances (RTI: 256 MB – federate: 128 MB)	# instances (RTI: 256 MB – federate: 256 MB)	# instances (RTI: 128 MB – federate: 256 MB)
1	65536	65536	65536
10	65536	65536	65536
20	60292	61092	63567
30	40423	43025	23301
40	29838	31878	-
50	25135	26126	-
100	13057	13246	15356

„The maximum number of object instances”

Internal characteristics



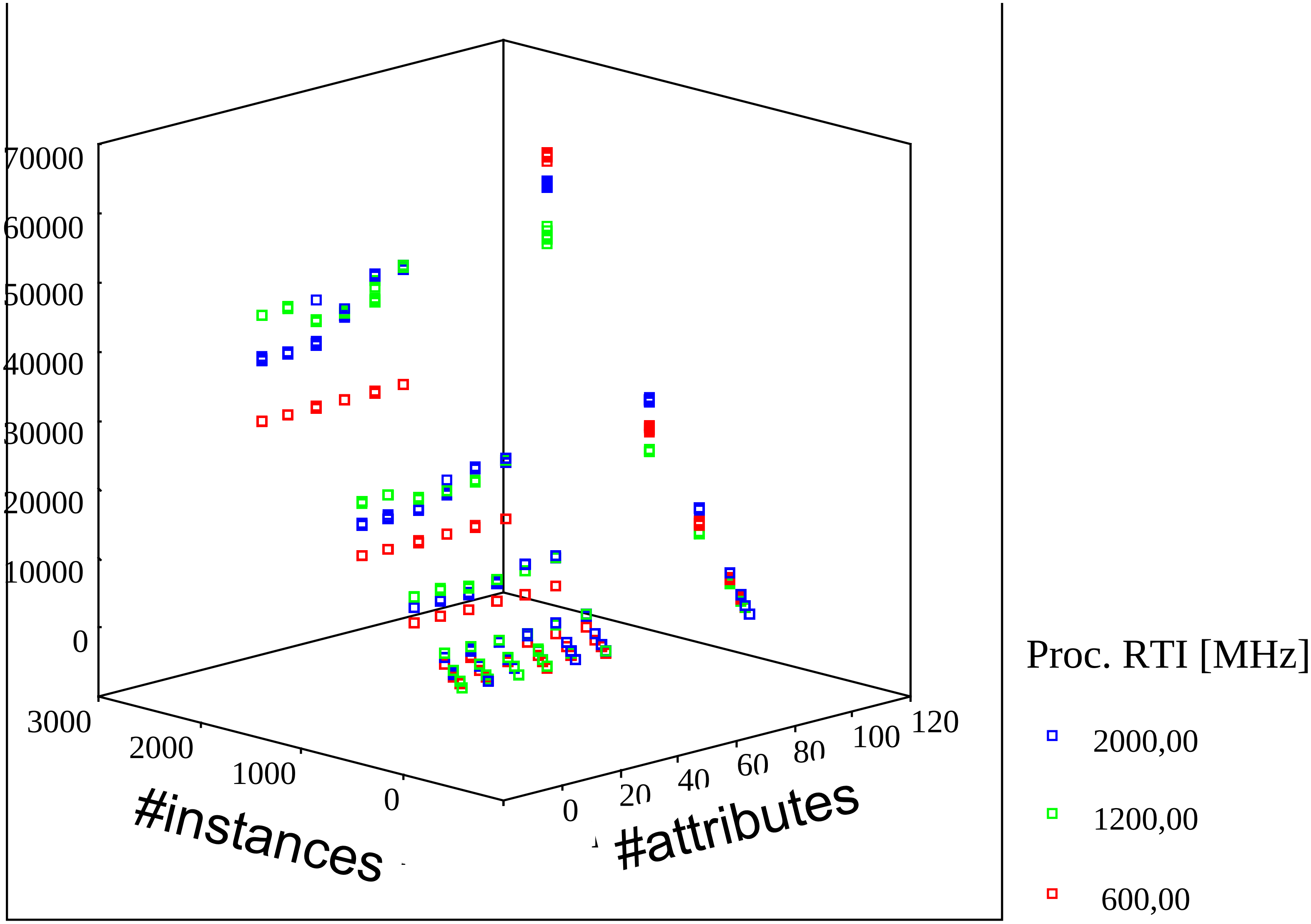
„The maximum number of object instances”

Internal characteristics

# instances	*average [ms]*	*minimum [ms]*	*maximum [ms]*	*gap [ms]*	*variance*
10	198,43	125,00	260,00	135,00	1077,07
20	451,50	437,00	469,00	32,00	136,27
50	1068,60	765,00	1392,00	627,00	34978,12
100	2141,18	1546,00	2784,00	1238,00	132804,51
200	4336,13	3093,00	5568,00	2475,00	489240,60
500	10803,68	7797,00	13920,00	6123,00	3278864,96
1000	21663,95	15639,00	27997,00	12358,00	13246349,88
2000	44076,12	31310,00	59659,00	28349,00	61135094,04

“Initialisation time of federate”

Internal characteristics



“Initialisation time of federate”

Poland

Internal characteristics

Regression model

independent variables	*unstandardized coefficients*		*t*	*significance*	*95% confidential level of B*	
	B	*standard error*			*lower bound*	*upper bound*
(constant)	-4239,35	200,631	-21,130	0,000	-4632,82	-3845,88
#instances	22,04	,098	223,871	0,000	21,85	22,23
# attributes	40,82	2,145	19,028	0,000	36,61	45,02
federate processor [GHz]	1,98	0,127	15,638	0,000	1,73	2,22

Initialization time = - 4239,35 + 22,04 * #instances + 40,82 * #attributes + 1,98 * federate processor [GHz]

"Initialisation time of federate"

Conclusions

- The environment is built as an opened system and can be easily developed and improved;
- The methodology of federation development and execution is synergy of three approaches:
  - mathematical modelling (operations research methods)
  - FEDEP
  - RUP
- The statistical analysis of the external and internal characteristics provides many indications for a federation developers and users.
- *MSCombat, which was modelled, designed and developed in our University enabled proper preparation of concept phase and took place in the formal competition, announced by Department of Armament Policy (part of MoD) and finally we have won the project realization.*